National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Annual Report on Vital Signs Monitoring of Glaciers in the Central Alaska Network, 2010

Natural Resource Technical Report NPS/CAKN/NRTR—2011/423

Annual Report on Vital Signs Monitoring of Glaciers in the Central Alaska Network, 2010

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Please cite this publication as:

Burrows, R. and G. Adema. 2011. Annual report on Vital Signs monitoring of glaciers in the Central Alaska Network, 2010. Natural Resource Technical Report NPS/CAKN/NRTR—2011/423. National Park Service, Fort Collins, Colorado

NPS 953/106533, January 2011

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List of Acronyms

APU	Alaska Pacific University
BY	Balance Year
CAKN	Central Alaska Network
DENA	Denali National Park and Preserve
ELA	Equilibrium Line Altitude
GPS	Global Positioning System
IHOG	Interagency Helicopter Operations Guidelines
NPS	National Park Service
PPK	post processed kinematic GPS survey
RPRS	Research Permit Reporting System
UAF	University of Alaska
WRST	Wrangell-St. Elias National Park and Preserve

List of Variables

b'	height of snow surface on stake
b'_0	height of snow surface on stake at initial time
b'_1	height of snow surface on stake at time 1
$b'ss$	height of summer surface on stake
$b_n(f)$	new firn with transient water subtracted out
b_n	net balance
b_{nI}	the net balance at the index stake
b_{nAELA}	the net balance at the ELA
b_s	summer balance
b_w	winter balance
$\Delta b_n / \Delta Z$	balance gradient
h_s	snow height/depth
ρ	snow density
S_{wi}	the irreducible water-volume constant, in other words the water retained in snow by capillary retention this is considered to be a ratio of 0.07 of the void space (Colbeck 1974)
t_0	initial time
t_1	time 1
V_e	emergence velocity
Z_0	glacier surface height at initial time
Z_1	glacier surface height at time 1
Z_{AELA}	the elevation of the long-term (average) ELA
Z_I	the elevation at the index stake

Executive Summary

During 2010, three main program goals were accomplished: (1) a draft revised monitoring protocol with several additions and changes to the monitoring protocol was completed, (2) long-term monitoring continued for the 20th consecutive year, and (3) cooperative agreements established with University of Alaska, Fairbanks (UAF) and Alaska Pacific University (APU) to develop a glacier inventory for Alaska, focusing on a glacier extent and volume change products over the next 3 years (see separate Research Permit Reporting System (RPRS) report). Glacier related research included the second year of a three year study to assess the impacts of human waste on the Kahiltna Glacier with APU (see separate RPRS report), analysis of 2006 LiDAR data and a 1970s Washburn topographic map of Muldrow Glacier continued by UAF, and a UAF M.S. student conducted mass balance measurements and installed a weather station on the lower Kahiltna Glacier (see separate RPRS report). This paper presents the 2010 glacier monitoring results for the Vital Sign program of the Central Alaska Network (CAKN).

- Long-term monitoring during the 2010 field season included Index Surveys. Fieldwork was conducted at DENA during two field campaigns, in May and September. The May campaign collected snow depth, snow density, glacier surface height, glacier stake height (in relation to the glacier surface), and precise stake position data at each index station on Kahiltna and Traleika Glaciers. The precise location of one survey monument on the lower Muldrow Glacier surface was GPS surveyed to track changes in surface height and glacier velocity. The September campaign collected glacier surface height, glacier stake height (in relation to the glacier surface), and precise stake position data at each index station.

  Reduction of the mass balance data shows a negative net balance at both index stations on each glacier. The negative mass balance adds to the overall negative trend in the cumulative balance since measurements started in 1991, although this year marks the reversal of a shorter term positive trend since 2004 on Kahiltna Glacier with 2009 marking the same reversal at Traleika.

  The surface speed of the Kahiltna Glacier at the index station was 195 m/year and 147 m/year at Traleika. The surface speed at the index station appears to be decreasing through time since 1991 on Kahiltna and increasing at Traleika with an unprecedented acceleration between May and September 2010.

  In addition, a GPS survey on East Fork Toklat Glacier collected glacier surface elevation data along a longitudinal profile, legacy mass balance stake location and heights, and several points to map the terminus position. Panoramic gigapixel photography was newly employed this year for several sites: 360 degree panoramas at the index stations (spring and fall) and Muldrow Glacier monument (spring); panoramas were taken from vantage points above the lower sections of East Fork Toklat, West Fork Cantwell (spring and fall); and one historic panorama at Oastler Pass above the lower Muldrow Glacier (spring)

- A GPS survey conducted on East Fork Toklat Glacier shows dramatic thinning of over 120 meters (400 feet) since the 1950s.

In addition, fixed wing over flight was conducted in March to search for surging glaciers. No glaciers were observed to surge during 2010.

Acknowledgments

Introduction: Background

Glaciers are a significant resource of mountain ranges in Alaska. The glacial resources of Denali National Park (DENA) and Wrangell-St. Elias National Park (WRST) are vast. Glaciers in DENA cover ~4,000 km^2, approximately one sixth of the area of the park. Glaciers in WRST cover ~13,000 km^2, approximately 25% of the park's area. They are integral components of the region's hydrologic, ecologic, and geologic systems. Compellingly, recent research indicates ice loss from Alaska mountains has been accelerating and significantly contributing to global sea level rise (Arendt et al 2002, 2008, Larsen et al 2009). Glaciers continue to be monitored as a prominent and integral Vital Sign of the CAKN program in the landscapes and ecosystems of these parks.

There are ten measurable objectives for glacier monitoring listed below. This report details results of monitoring efforts at DENA leading to these objectives for the 2009/10 balance year. The balance year was from October 1, 2009 to September 30, 2010.

> All Glaciers:
> - extent/area at 10-year intervals (equilibrium line altitudes (ELAs) are determined when possible);
>
> Selected Glaciers:
> - terminus morphology and longitudinal profile mapping.
> - general condition of selected glaciers via repeat photography;
> - assess ELAs on a yearly basis at selected glaciers throughout DENA;
> - identify surging glaciers and take measurements when possible;
>
> Index Glaciers:
> - winter balance at index stations;
> - summer balance at index stations;
> - net mass balance at index stations;
> - twice yearly surface elevation at index stations;
> - twice yearly glacier surface velocity near index stations;
> - assess surface cover in late fall for each index glacier;

Methods

Extent

Comparative Photography
We incorporated high resolution digital panoramic photography (also known as gigapixel panoramic photography) into the program this year. Details of these methods are described in the corresponding standard operating procedure of the new protocol (Adema and Burrows, in progress). Rob Burrows and Guy Adema took photos of East Fork Toklat Glacier, West Fork Cantwell Glacier, Muldrow Glacier, Traleika Glacier, and Kahiltna Glacier. Dates, coordinates, and other metadata are in Table 1 (presented below in the results section) for each of these sites.

GPS Survey Mapping

On September 21, Rob Burrows and Andrew Ackerman conducted a post-processed kinematic GPS (PPK) survey on the East Fork Toklat Glacier using two Trimble R6 receivers. Historic survey point, NATASHA, served as the GPS base station for the duration of the roving survey on the glacier. They walked a longitudinal profile, occupying previously surveyed coordinates and new ones on the profile. In addition, when old mass balance stakes were spotted or encountered they recorded the stake name (if available), height above the surface, and surveyed the coordinates at the base of the stake.

The GPS data was post-processed using Trimble Business Office software. The base station data was processed against the National Geodetic Survey's Continuously Operating Station data at Healy, AK (GRNX) for precise coordinates of NATASHA. Then the rover data was post-processed against the NATASHA base station data.

Index Station Measurements

The index stations on Kahiltna and Traleika Glaciers were visited three times each this year. The methods for index stations are described in detail in Mayo (2001). See Figure 1 for a visual representation of the methods and instruments, and Figures 2 and 3 for locations of index station. The first visit is designed to capture the maximum winter balance and occurred on May 18 on Traleika Glacier and May 19 on Kahiltna Glacier. This May field campaign collected snow depth, snow density, glacier stake height (in relation to the glacier surface), glacier surface height, precise stake position data at each index station, and 360-degree gigapixel panoramas on Kahiltna and Traleika Glaciers.

The fall visits, designed to capture the minimum balances for the year, occurred on September 12 on Traleika Glacier and September 14 on Kahiltna. The September campaign collected glacier surface height, glacier stake height (in relation to the glacier surface), precise stake position data, and 360-degree gigapixel panoramas at each index station. We returned to both sites on September 15 to place new ablation stakes up glacier from the previous stakes. The new Kahiltna stake name is K17-10-6M and is composed of three 2-meter long sections. On the Traleika glacier the new stake name is T-10-7M and is composed of one bottom 3-meter long section and two upper 2-meter long sections.

Mass Balance

Glacier mass balance terms and variables used in this report follow the convention of Ostrem and Brugman (1991). Balance (b) is a change in mass measured at a point (at a stake) on the glacier for one or more periods of time. By convention the balance year (BY) is the period between two successive times of minimum balance in late fall. The BY is designated by the calendar year in which it ends.
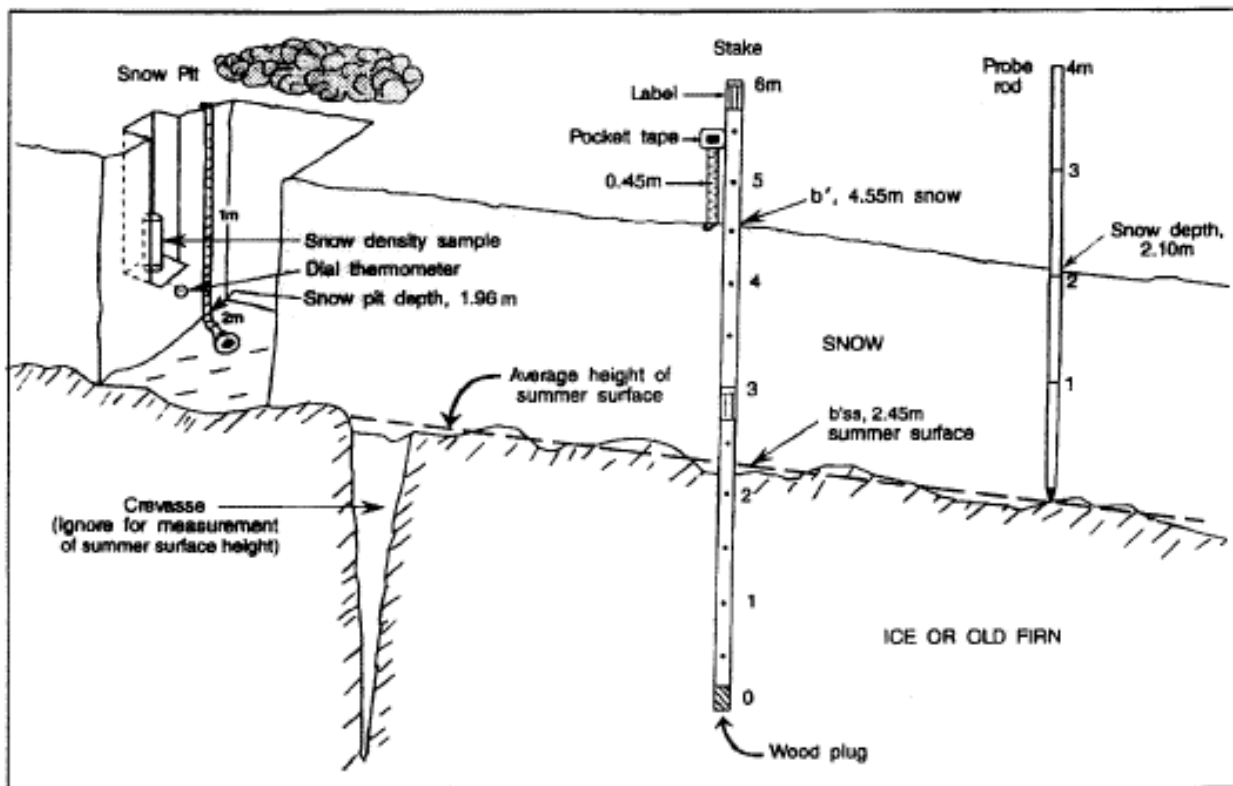
Figure 1. An illustration of the measurements taken and instruments used at an index stake. See text and protocol for further explanation. From Mayo (2001).

Accumulation includes all processes that add mass to the glacier such as snowfall, wind drifting, avalanching, rime ice buildup, rainfall, superimposed ice, and internal accumulation. Winter balance (b_w) is the sum of all accumulation and ablation during the winter season (also referred to as the accumulation season). At the equilibrium lines of the index glaciers the time of maximum winter balance typically occurs in mid to late May. The b_w is the product of accumulated snow depth or height of snow, (h_s) between the upper surface to the previous year's summer surface and the snow density (ρ) at a single point on the glacier surface.

$$b_w = h_s\rho \hspace{3cm} \text{(eq. 1)}$$

The summer surface is the surface of firn and/or ice on which the new winter season's snow is deposited. A dirty layer and significant change in density typically identify it. The height of the summer surface, as measured by the distance from the base of the stake, is designated b'ss. Likewise the height of the snow surface is designated b' (Figure 1), such that:

$$h_{snow} = b' - b'ss \hspace{3cm} \text{(eq. 2)}$$

Ablation includes all processes that remove mass from the glacier such as melting and runoff, evaporation, sublimation, calving, and wind erosion. The summer balance (b_s) includes the total of all ablation and accumulation during the summer season at a single point on the glacier surface (always a negative value as indicated below).

$$b_s = -(h_{snow}\rho_{snow} + h_{firn}\rho_{firn} + h_{ice}\rho_{ice}) \hspace{1.5cm} \text{(eq. 3)}$$

Summer balance is determined at the end of the BY. At the equilibrium line of the index glaciers

this typically occurs during the period of mid August to mid September. The symbols b_w and b_s refer to values measured and/or calculated at a stake or other measurement point. Likewise the local net balance (b_n) is the change in balance calculated at a measurement point during one BY. These balance values are expressed in meters water equivalent (m w.e.).

$$b_n = b_w + b_s \hspace{3cm} \text{(eq. 4)}$$

In positive balance years the seasonal snow remaining at the end of the summer season is called new firn. This remaining quantity is equivalent to a positive b_n calculated in eq. 4. Snow that becomes new firn is a mixture of ice crystals, liquid water, and air. However, the liquid component is in temporary storage. Some of it is converted into internal accumulation by freezing during the next winter (Trabant and Mayo 1985); the rest drains from the glacier as the firn gradually compresses into glacier ice. The liquid component of new firn creates a potential problem in glacier mass balance accounting, because the same material could be counted twice, once in the new firn, and a second time when it freezes. Thus, the liquid component is subtracted from the snow balance when snow becomes new firn. The amount of ice (without water) in new firn, $b_n(f)$, is found by subtracting the water volume retained by capillary retention from the arithmetic b_n of eq. 4.

$$b_n(f) = b_n - S_{wi} [h_{snow}(1-\rho_{snow}/\rho_{ice})] \hspace{1.5cm} \text{(eq. 5)}$$

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where:

h_{snow} of eq. 2, is the remaining snow at the end of the summer season.

S_{wi} is the irreducible water-volume constant, in other words the water retained in snow by capillary retention this is considered to be a ratio of 0.07 of the void space (Colbeck 1974).

Equilibrium Line Altitude

Fluctuations in the ELA from year to year signal annual fluctuations in climate and is the best indicator for comparison of long term trends and with other glaciers in Alaska. The annual ELA can be determined in two ways. The first method is to observe the elevation of the transient snow line at the end of the summer season. This may be ambiguous if this is not a well defined line or zone and/or if one cannot discern the current year's snow from previous years. In addition, it may become completely obscured with early snow fall. The more accurate method to determine the annual ELA is to find the altitude at which $b_n = 0$. Ideally this is calculated using two or more mass balance stakes to determine the balance gradient, $\Delta b_n/\Delta Z$, for the glacier for the year. In the case where balance is measured at one site, a balance gradient is assumed. Fortunately, balances were measured at two sites on both Kahiltna and Traleika glaciers for 4 and 5 years, respectively in the 1990s (Mayo 2001). The average balance gradient, $\Delta b_n/\Delta Z$, from this data is used to find the ELA:

$$ELA = Z_I - b_{nI} (\Delta b_n/\Delta Z) \qquad \text{(eq. 6)}$$

Where: Z_I is the elevation at the index stake and b_{nI} is the net balance at the index stake.

Similarly, the net balance at the long term average ELA is found using the same principles and is also a useful value to compare with results from monitoring programs on other glaciers:

$$b_{nAELA} = b_{nI} - [\Delta b_n/\Delta Z (Z_I - Z_{AELA})] \qquad \text{(eq. 7)}$$

Long term average ELAs for the Kahiltna and Treleika glaciers are shown in Figures 2 and 3.

Glacier Motion

Glacier motion was detected by conducting repeat GPS measurements on the ablation stake at each visit. Glacier speed is calculated simply by taking the quotient of the distance traveled and time between measurements. Emergence velocity (V_e) is the rate at which ice is emerging or firn is being buried at the stake location.

$$V_e = [(Z_1 - Z_0) - (b'_1 - b'_0)]/(t_1 - t_0) \qquad \text{(eq. 8)}$$

Where: t_1 and t_0 are the later time and initial time, respectively.

Z_1 and Z_0 are the glacier surface heights at a later time and an initial time, respectively.

b'_1 and b'_0 are the glacier stake heights at a later time and an initial time, respectively.

Glacier Surface Height

Glacier surface height at each index station is measured as described in the protocol by taking GPS measurements on the surface at approximately equidistant points of a triangle surrounding the fixed index coordinate. Surface height at the index station for that visit is then simply the average height of those three measurements. Changes in surface height are then the difference of the average height.

Surging Glacier Observations

Efforts to record glacial surge activity took several forms. Rob Burrows conducted a search for surging glaciers in DENA with Pilot Colin Milone in the NPS Husky airplane on March 23, 2010. Figure 4 shows the approximate flight path. One survey monument marker on the surface of the lower Muldrow Glacier was reoccupied for a fast-static GPS survey on May 19, and a 360 degree gigapixel panorama was captured at this site. The lower Muldrow Glacier was also photographed in panorama from Oastler Pass.

Figure 2. The Kahiltna Glacier system and surrounding glaciers from 2000 Landsat imagery and associated mapped glacier margin. The glacier equilibrium line altitude (ELA) is approximate, based on almost 20 years of long term mass balance monitoring. The laser profile refers to the path flown and line measured for repeat surface elevation surveys by UAF researchers.**.**
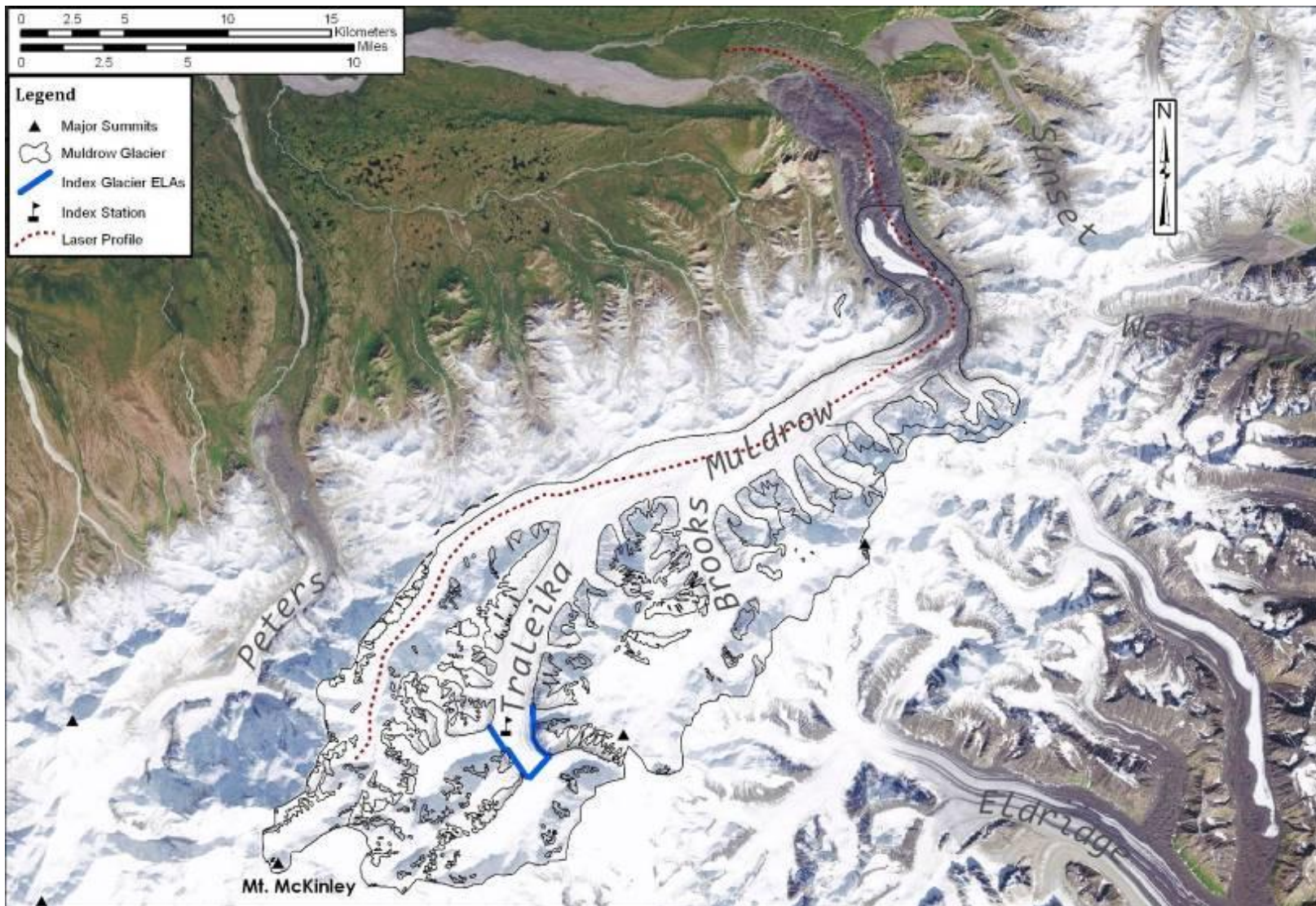
Figure 3. The Muldrow Glacier system and surrounding glaciers from 2000 Landsat imagery and associated mapped glacier margin. The glacier equilibrium line altitude (ELA) is approximate and based on almost 20 years of long term mass balance monitoring. The laser profile refers to the path flown and line measured for repeat surface elevation surveys by UAF researchers.
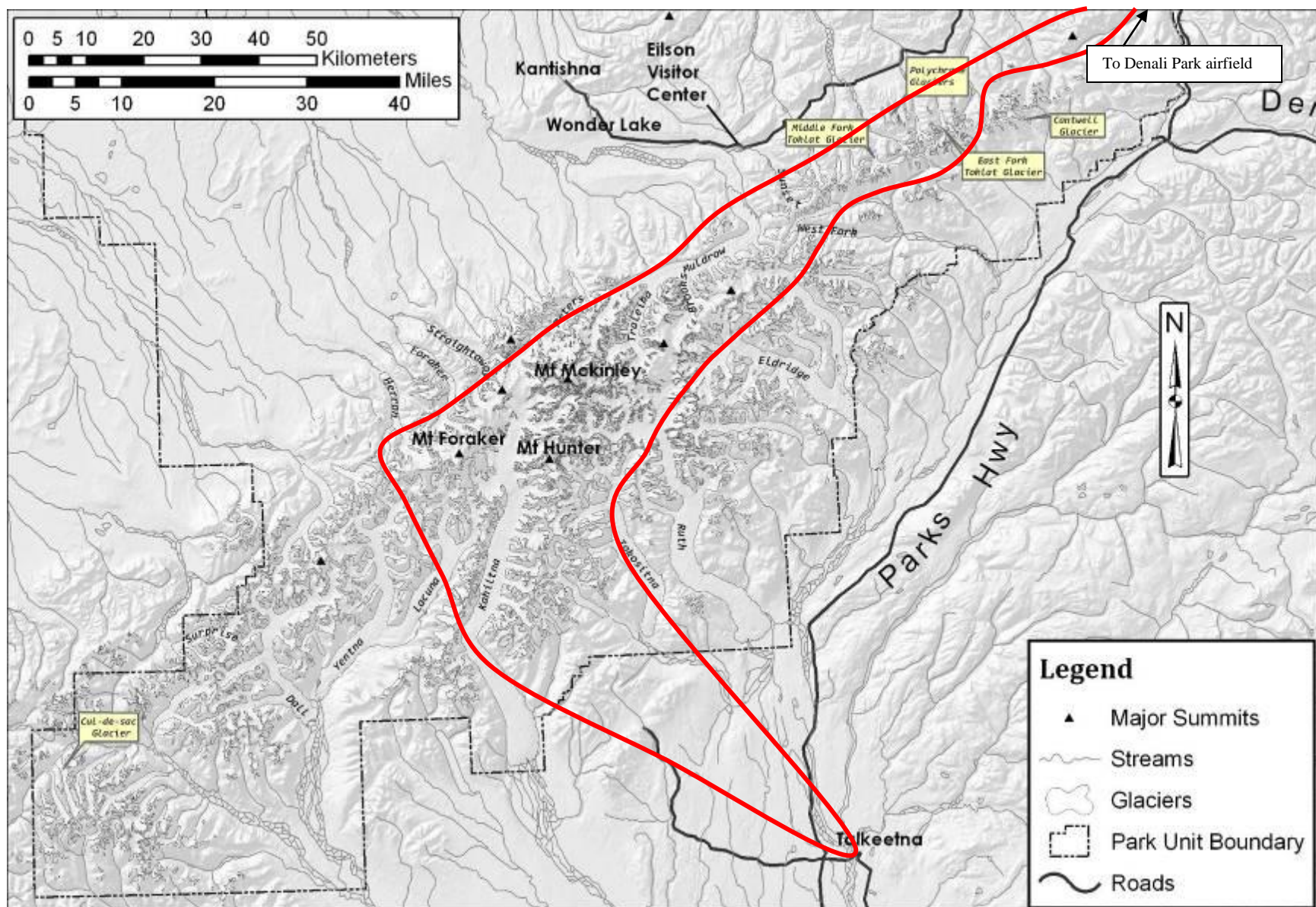
Figure 4. Glaciers of interest in Denali National Park and Preserve. Glacier margins are from 1950s air photos. The red line is the approximate flight path for the glacier surge search overflight in March.

Results

Extent

Comparative Photography
We photographed panoramas from 11 sites during the field campaigns this year (Table 1). See Figure 4 for locations of these glaciers in DENA. These are difficult to convey in a written report, however, thumbnails of each panorama are in Appendix A. At the date of this writing, the panoramas can be viewed from any computer with a high speed internet connection on the Gigapan website, http://www.gigapan.org/profiles/27054/. The Gigapan platform allows the viewer to zoom in on any area of interest at up to the level of detail captured by the camera lens.

Lower resolution 360 degree panoramas have been taken in previous years from the index sites and were compiled into comparison images this year (see Appendix A for these). One historical panorama of the Muldrow Glacier from Oastler Pass was duplicated this year, and is presented in comparison with the previous panoramas taken in 1925 by S.R. Capps and 2004 by R.D. Karpilo in Appendix A.

No analysis was done from the photography this year. However, to demonstrate the ability to see changes between photographs we chose the West Fork Cantwell Glacier, which shows seasonal changes in snow and ice cover (Figure 5) and terminus retreat between May and September 2010 (Figure 6).

GPS Survey Mapping
The path we walked and the points surveyed on the East Fork Toklat Glacier on September 21 are shown in Figure 7. This data is in Appendix B. Analysis of the data and comparisons to historic data will be completed in 2011.

Equilibrium Line Altitudes
Snowfall in late August fell to a low enough elevation that it obscured the end of season ELA for most observed glaciers during the fall field campaign; however ELAs estimates are calculated from the index station data (see Table 2 below). Likewise, on East Fork Toklat Glacier new snow made it difficult to determine the ELA.

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Table 1. Metadata for panoramic photography taken in the 2010 field campaigns. See Appendix A for thumbnails of the photographs and http://www.gigapan.org/profiles/27054/ to view the full gigapixel panoramas from anywhere with high speed internet.

Glacier	GPS Point Name	Date	Coordinates		Elevation (ft)	Field of View		Image Size gigapixels	Lens focal length (mm)	# of images	Comments
			Latitude - N	Longitude -W		Horiz.	Vert.				
Kahiltna	KPAN	5/19/2010	62.94121	151.24586	6339	360	129	0.86	48	240	Taken at the Index Station
Kahiltna	Kpanfall	9/14/2010	62.9415	151.24605	6354	360	108	4.24	120	1002	
Traleika	TLK PANPP	5/18/2010	63.12665	150.78655	6896	360	125	1.79	50	608	Taken on the medial moraine between the stake and the index coordinate
Traleika	Trapanfall	9/12/2010	63.1265	150.7865	6924	360	89	3.6	120	900	Taken on the medial moraine between the stake and the index coordinate
Muldrow	MUL2PAN	5/18/2010	63.27022	150.42147	4382	360	68	0.47	50	138	near the Muldrow 2 Survey Monument
Muldrow	OASPAN	5/18/2010	63.24123	150.67295	5679	243	97	0.52	50	112	Muldrow Glacier from Oastler Pass
East Fork Toklat	EFPAN2010	5/19/2010	63.43954	149.66362	4661	248	90	0.07	135	432	upper right lateral moraine
East Fork Toklat	EFPAN10FALL	9/15/2010	63.45192	149.6638	4630	186	57	0.67	90	152	on the right lateral moraine down valley from the spring photo viewpoint.
East Fork Toklat	EFPAN10FALL	9/15/2010	63.45192	149.6638	4630	92	40	0.42	120	82	zoomed in on the large shadowed area around the terminus
West Fork Cantwell	CANPAN2010	5/19/2010	63.43509	149.36333	3812	183	63	0.52	75	138	
West Fork Cantwell	CANPAN10FL	9/12/2010	63.43514	149.36379	3731	135	70	1.07	120	246	On the small moraine just below the spring photo viewpoint
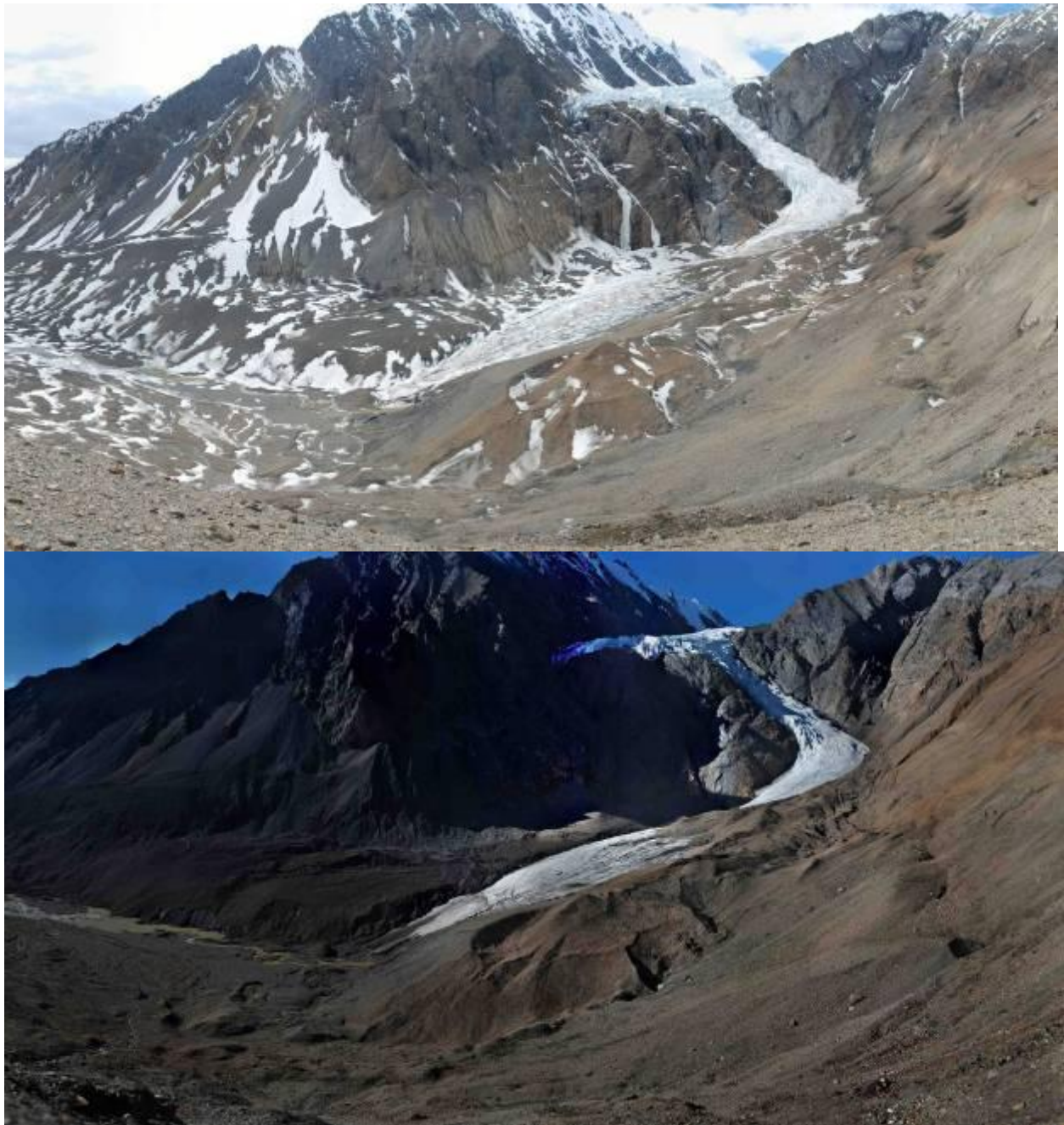
Figure 5. Comparison of panoramic photography of West Fork Cantwell Glacier between May 19 (top image) and September 12, 2010 (bottom image).

Figure 6. Comparison of the terminus of West Fork Cantwell Glacier between May 19 and September 12, 2010.
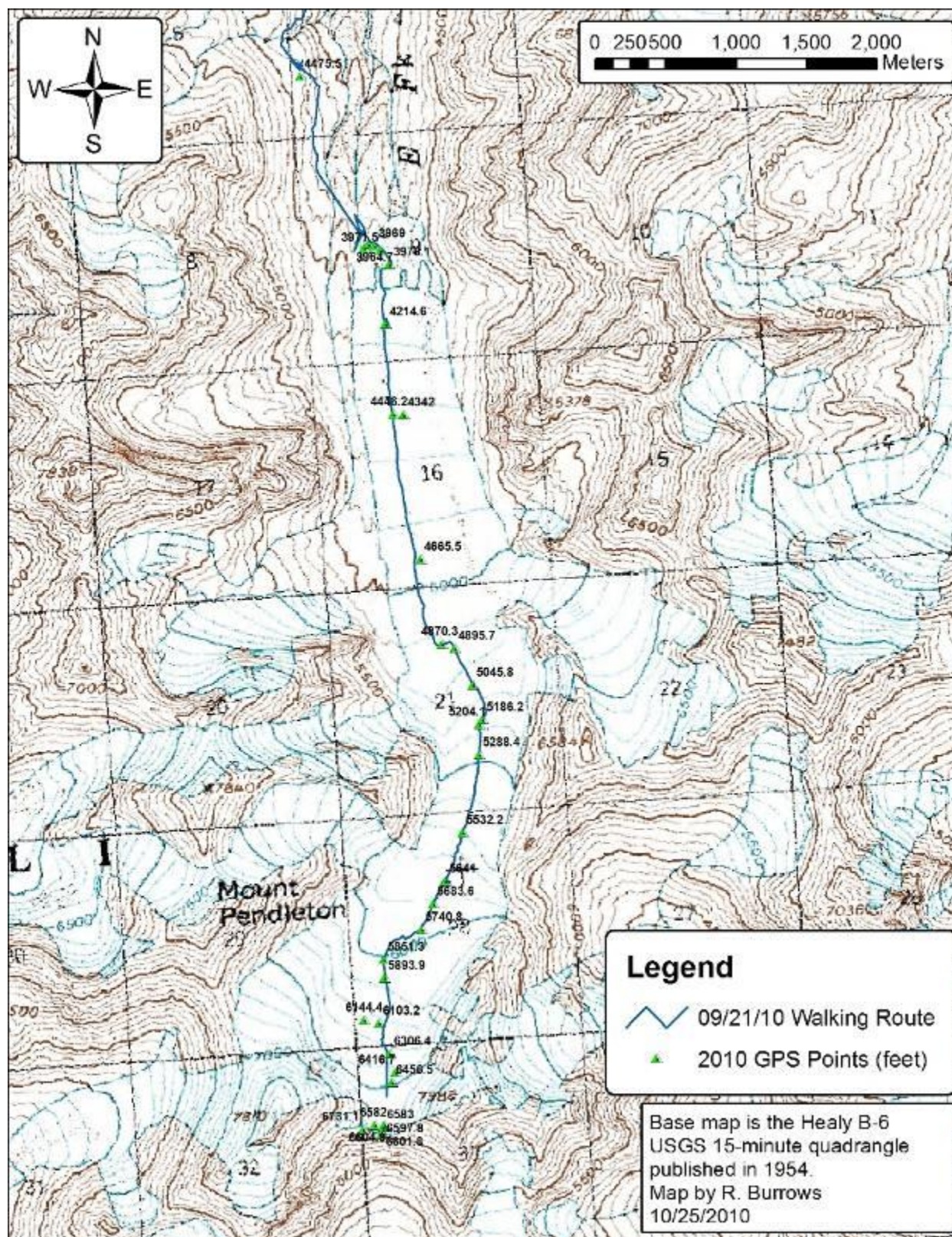
Figure 7. Map showing the GPS survey on East Fork Toklat Glacier on 09/21/2010. The numbers by each point are the 2010 measured surface height (in feet for easy comparison with the map).

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Index Station Measurements

Mass Balance

Balances at the index stakes are shown in Table 2. Raw and intermediate data and field datasheets are included in Appendix C

Table 2. Balance data for the index stakes in 2010.

Glacier	Stake Name	Measure Date	b_w (m w.e.)	b_s (m w.e.)	b_n (m w.e.)	Balance Gradient (m w.e./m elev)	ELA Estimate (meters)
Kahiltna	07-K17-6M	5/19/10	0.63				
		9/14/10		-1.03	-0.41	0.0023	2104
Traleika	07-T-6M	5/18/10	0.53				
		9/12/10		-2.04	-1.51	0.0046	2427

Glacier Motion and Surface Height

At Kahiltna Glacier, the index stake moved 63 m between May 19 and September 14 resulting in a speed of 195 m/year. At Traleika, the stake moved 47 m between May 18 and September 12 resulting in a speed of 147 m/year.

The surface height at the Kahiltna index station coordinate was 1938.6 m on May 19 and 1936.7 m on September 14 resulting in a change of -1.9 m. On May 18 the surface height at the Traleika index station coordinate was 2098.2 m and 2096.1 m on September 14 resulting in a change of -2.1 m. The emergence velocities were -4.8 m/yr and +5.8 m/yr for Kahiltna and Traleika respectively for the summer season.

Surging Glacier Observations

No glaciers were observed to be surging on any of the flights, nor were any reported this year. The approximate flight path is shown on Figure 1. However, to record the state of the Muldrow Glacier the location of monument 2 on the lower glacier was recorded using high precision GPS on May 18. See Table 3 for these coordinates and a summary of surface speed since 2006. In addition, two gigapixel panoramas were taken during the May campaign one at monument 2 and, as mentioned above, from Oastler Pass.

Table 3. Coordinates and surface speed of monument 2 on Lower Muldrow Glacier.

Date (mm/dd/yyyy)	Elapsed time (yr)	Latitude	Longitude	Surface Speed (m/yr)
8/23/2006				
8/20/2007	0.99	63.26956596	-150.42350532	
6/1/2008	0.78	63.26975975	-150.42284190	51
9/1/2008	0.25	63.26984047	-150.42252640	72
9/1/2009	1.00	63.26989638	-150.42225617	15
5/18/2010	0.71	63.27001523	-150.42175527	40

Discussion

East Fork Toklat Glacier

Comparison of this year's GPS survey with the 1954 U.S. Geological Survey 15-minute quadrangle, Healy B-6, shows substantial thinning below 6100 feet elevation along the approximate centerline of the glacier, with over 120 meters (400 feet) of thinning in the terminus area (Figures 7 and 8). The 2010 terminus of active ice (debris covered) is at about the same position as the 1954 bare ice margin, however there was ~140 meters (450 feet) of surface lowering here during the 56 year period, so it is likely the active ice terminus was down valley from this. Future analysis with 1950s air photos should elucidate this ambiguity.

Index Station Data

While the index stations were situated in an attempt for them to represent the balance of the entire glacier, the terrain dictated that they could not be located right at the long-term ELAs. At Kahiltna Glacier, the index station had to be located above the long-term ELA because of an icefall/highly crevassed zone at that elevation/location, see Figure 3 (Mayo 2001). Thus the b_n tends to be higher than that of the area averaged value of the entire glacier. At Traleika, the index station is located below the long-term ELA because at that location is the confluence of two major tributaries (Figure 4). It was thought that it would be better to capture the behavior of the main trunk glacier rather than just one tributary (Mayo 2001). Here the b_n tends to be more negative than of the entire overall.

The b_w for the Kahiltna Glacier index stake for 2010, 0.63 m w.e., is 58% of the 19-year average and that for Traleika, 0.53 m w.e., is 79% of average. The 2010 stake b_s for Kahiltna, -1.03 m w.e., is 108% of average and for Traleika, -2.04 m w.e., is 155% of average. Because the net balance can be positive or negative, calculating the percent of average is not a meaningful measure. Instead the net balance is normalized compared to the average and historical minimum and maximum. Using this measure yields a percentage above or below the average, for example the highest b_n so far has a normalized value of 100% whereas the lowest value has a normalized value of -100%. For this balance year the b_n for Kahiltna index stake is -0.41 m w.e. and thus
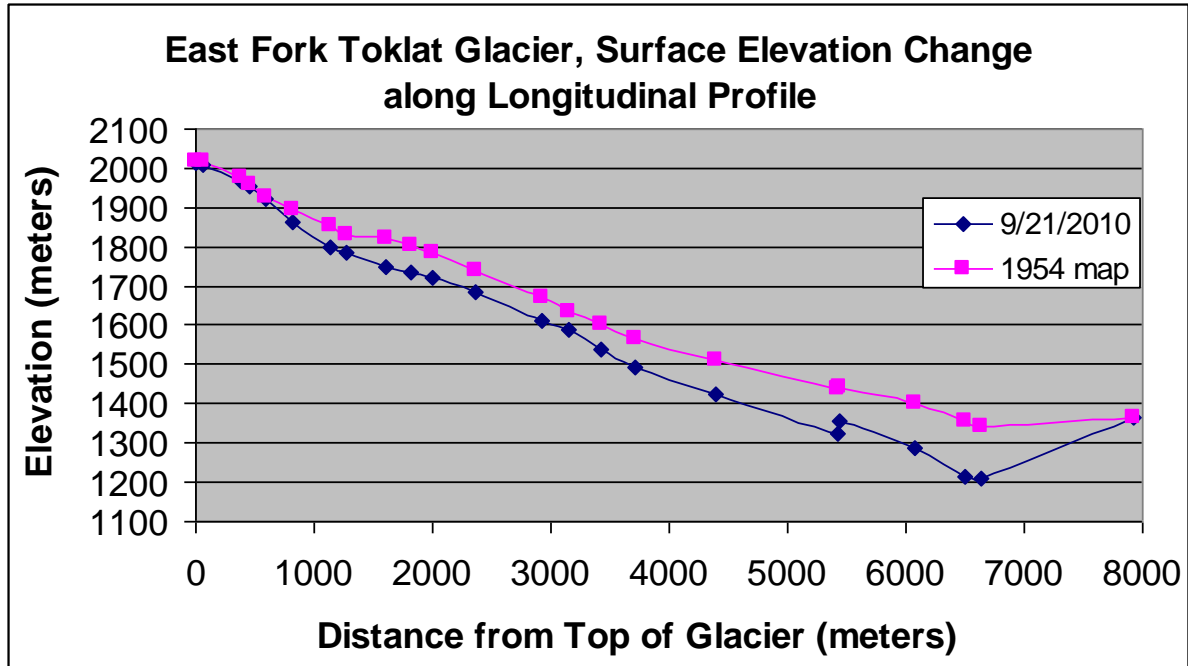
Figure 8. Elevation of the longitudinal profile from the 1954 Healy B-6 USGS quadrangle and from the 9/21/10 GPS survey. Note the good agreement between control points on bedrock at the top and bottom of the profiles.

has a normalized b_n index of -47% and for Traleika the b_n is -1.51 m w.e. and a normalized b_n index of -66%. In other words, of all the negative net balance years, Kahiltna 2010 b_n is 47% the value of the most negative balance year, likewise Traleika is 66% the value of the most negative.

Note that the b_n values are NOT necessarily indicative of the balance of the entire glacier for the year, but they do give an indication of the relative magnitude of the balance of each glacier.

Figures 9 and 10 also help put the 2010 data into context. This year was a negative balance year at both index stations (Figure 9). The long-term trends are chosen to be represented by the altitude of the ELA, which is calculated from the mass balance at an index stake and an estimated balance gradient (Figure 10). The ELAs were above average, reinforcing the negative trend of the last 19 years, but reversing a short-term lowering trend since 2004 at both glaciers (Figure 10).

Surface speed data are consistent with the long term trends (Figure 11). However, Traleika had an anomalously high speed between May and September 2010. We believe this value is correct and possibly a result of above average rainfall during the summer.
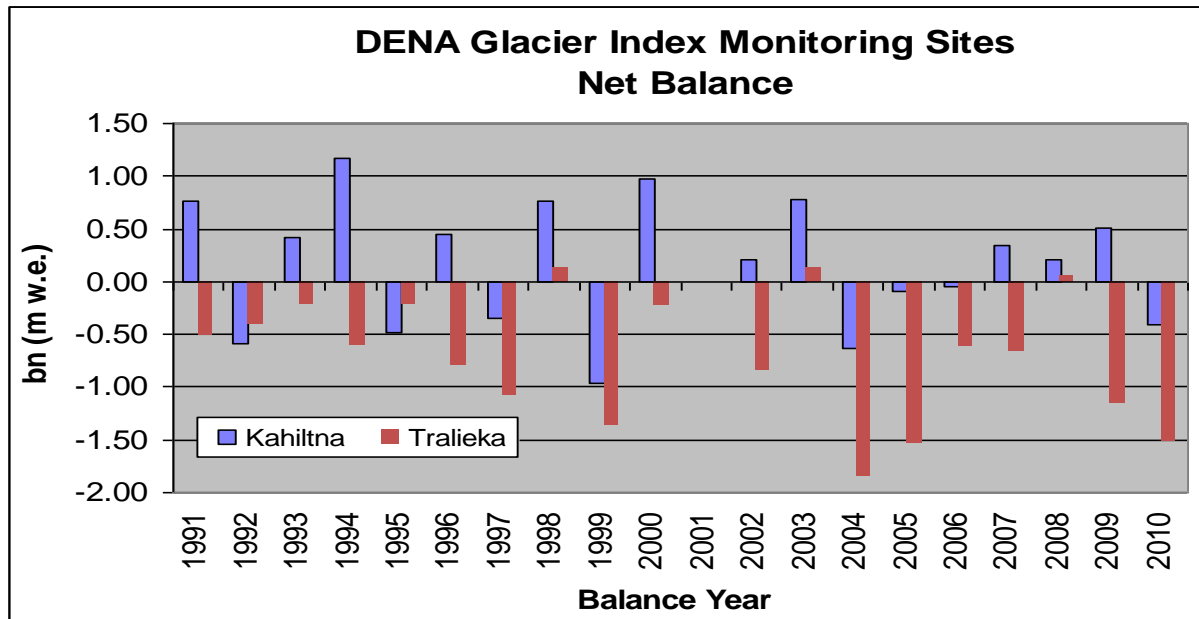
Figure 9. Net balance at the index stakes on Kahiltna and Traleika Glacier. Note that these values are NOT indicative of the balance of the entire glacier for the year, but they do give an indication of the relative magnitude of the balance of each glacier for the entire year.
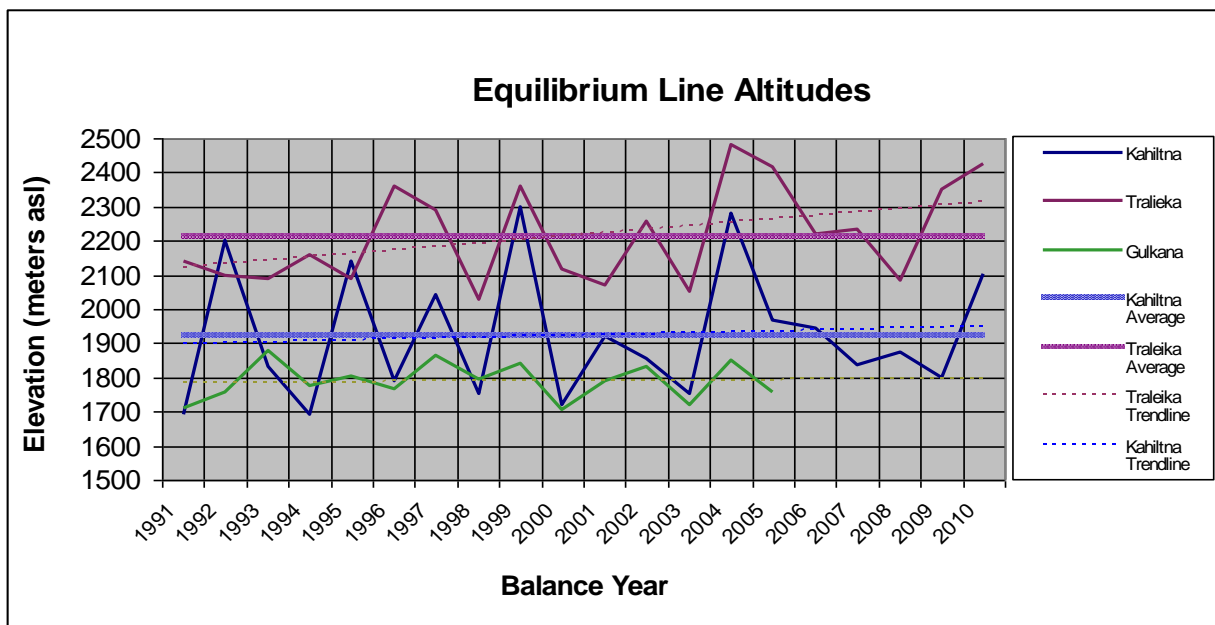
Figure 10. The calculated ELAs at each glacier. These values serve as an index of the entire glacier net balance for each balance year, and are a good comparison with patterns and trends on Gulkana Glacier, which is monitored by the US Geological Survey.

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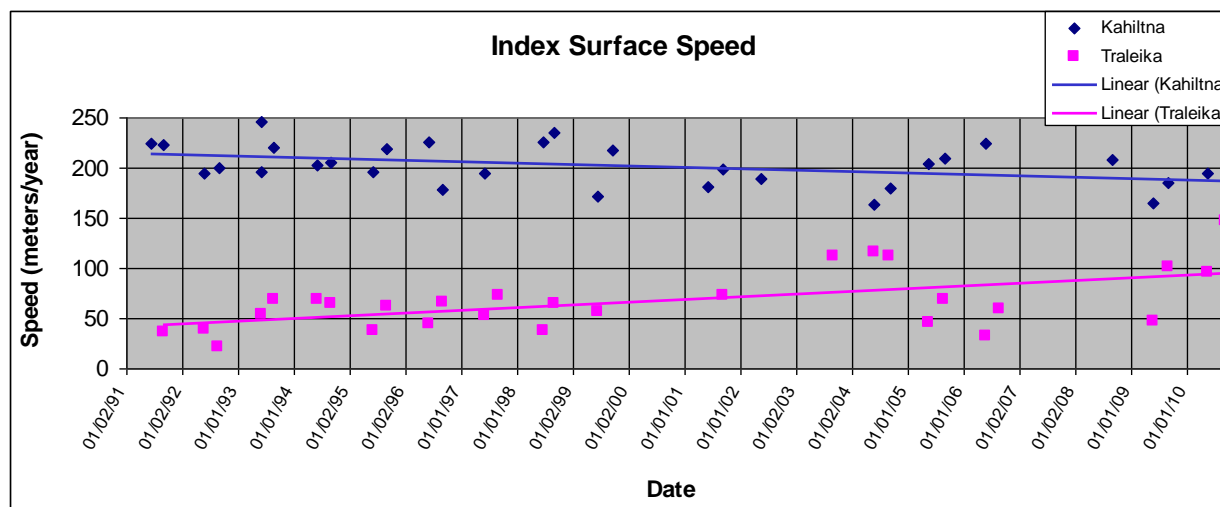
Figure 11. Surface speed of the index stakes on Kahiltna and Traleika Glaciers since 1991. Note the anomalously high speed of Traleika in late 2010.

Other Research Conducted

Waste Monitoring on the Southeast Fork of Kahiltna

Alaska Pacific University (APU) researcher Dr. Michael Loso and his graduate students are characterizing the glacier flow around Kahiltna Basecamp on the Southeast Fork of the Kahiltna Glacier, in order to assess the potential effects of human waste deposited in crevasses while climbers are on Mt. McKinley. This three-year cooperative agreement is assessing glacier dynamics of human waste and the associated biological risk to backcountry visitors and local watershed, in order to inform mountain waste management practices. In 2009, Loso and students created a preliminary flow map for the base camp area and located a buried latrine using a magnetometer (a magnet was installed in the latrine anticipating the tracking of its movement). In 2010, the APU researchers will characterize the glacier's mass balance and ice dynamics around key waste disposal sites and aircraft landing zones on the Kahiltna and other glaciers, assess the physical and chemical breakdown and fate of human waste in glacial environments and nearby, and review existing published literature and best management practices regarding human waste disposal in remote arctic environments. One product of the investigation will be a compilation of all known research results about the Kahiltna Glacier.

Kahiltna Mass Balance Characterization

Joanna Young, a M.S. student working under Dr. Anthony Arendt at University of Alaska Fairbanks is assessing the mass balance on Kahiltna Glacier. She placed balance stakes on the glacier below the ELA in May and checked them again in late August. She also set up a weather station on the lower glacier. The balance and meteorological data will help to validate a mass balance model for the area glaciers, and generate glacier runoff estimates.

Laser Altimetry

Dr. Chris Larsen of the University of Alaska Fairbanks collected topographic profiles of selected glaciers this year using airborne laser altimetry/LiDAR swath mapping technology.

Muldrow Volume Change Analysis

Dr. Chris Larsen is also working on a volume change analysis of the Muldrow Glacier based on previous post-1956-surge maps made by Bradford Washburn, LiDAR mapping of the lower glacier in 2006, and results from previous years' laser altimetry profiles. In support of this analysis, the Geo Spatial Services Project Center of St. Mary's University of Minnesota delivered DEMs and ESRI Geodatabase files generated from georeferenced digital scans of the Washburn maps.

Glacier Assessment in the Kichatna Range

Joe Bickley, an independent wilderness guide and glacier enthusiast spent some time in the remote Kichatna Mountains this summer. He mapped selected glacier termini using GPS, repeated historic glacier photographs, and collected GPS coordinates for repeat photo point locations from which to track glacier change into the future.

Plans for Coming Year and Recommendations

Long-term monitoring of glaciers in CAKN will continue in 2011 much the same as 2011 following and refining the protocol and standard operating procedures that we developed this year (Adema and Burrows, in progress).

We will obtain gigapixel photography on a new suite of glaciers, including the Kahiltna Glacier terminus, Middle Fork Toklat Glacier, Polychrome Glacier. Along with the photography, we plan to resurvey the termini of these glaciers and, if possible, completely re-map the Polychrome Glacier.

Additional data at the index stations will aid in interpreting past years' data: 1) We will conduct more extensive GPS surveying of the glacier surface elevation in the vicinity of the index stations. This data will aid in interpreting past surveys, since these are spread out up to several hundred meters apart and from the index station coordinate. 2) If weather, time, and helicopter logistics allow, we will conduct more extensive snow probing on the Traleika Glacier to explore patterns of snow accumulation and how representative the index stake is of the area of the glacier at which it resides.

See Appendix G – Logistics Notes for recommendations on improvements on the details and logistics for operations.

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Appendix A –Panoramas for 2010

Figure A-1. Muldrow Glacier from Oastler Pass on 05/18/2010. Camera location: 62.24123 degrees N, 150.67295 degrees W, 1732 m (5680 ft).

Figure A-2. Panoramas from Ostler Pass Viewpoint. Top photo was taken in 1925 by S.R. Capps, middle photo by Karpiro, 2004 and the bottom image is cropped from Figure A-1 (taken 5/18/2010)

Figure A-3. A 360 degree panorama from near the Mul 2 survey monument on the lower Muldrow Glacier, 05/18/2010. Camera location: 63.27022 degrees N, 150.42147 degrees W, 1336 m (4382 ft).

Figure A-4. East Fork Toklat Glacier, 05/19/2010.   Camera location: 63.43954 degrees N, 149.66362 degrees W, 1421 m (4661 ft).

Figure A-5. East Fork Toklat Glacier, 09/15/2010. Camera location: 63.45192 degrees N, 149.6638 degrees W, 1411 m (4630 ft).

Figure A-6. The terminus area of the East Fork Toklat Glacier, 09/15/2010. From the same camera location this is zoomed into the big shadow in the photo of Figure 5.

Figure A-7. West Fork Cantwell Glacier and valley, 05/19/2010. Camera location: 63.43509 degrees N, 149.36333 degrees W, 1162 m (3812 ft).

Figure A-8. West Fork Cantwell Glacier, 09/12/2010. Camera location: 63.43514 degrees N, 149.36379 degrees W, 1138 ft (3731 ft).

Figure A-9. A 360 degree panorama near the index station on Kahiltna Glacier, 05/19/2010. Camera location: 62.94121 degrees N, 151.24586 degrees W, 1933 m (6339 ft)

Figure A-10. A 360 degree panorama near the index station on Kahiltna Glacier, 09/14/2010. Camera location: 62.9415 degrees N, 151.24605 degrees W, 1937 m (6354 ft)

Figure A-11. A 360 degree panorama on the medial moraine near the index station on Traleika Glacier, 05/18/2010. Camera location: 63.12665 degrees N, 150.78655 degrees W, 2102 m (6896 ft).

Figure A-12. A 360 degree panorama on the medial moraine near the index station on Traleika Glacier, 09/12/2010. Camera location: 63.1265 degrees N, 150.7865 degrees W, 2111 m (6924 ft).

Kahiltna Glacier Index Site Panoramas

Fall 2004

Fall 2005

Fall 2008

Fall 2009

Figure A-13. Comparison of 360 degree panoramas taken during the fall visit to the Kahiltna Index Station in 2004, 2005, 2008, and 2009.

Figure A-14. Comparison of 360 degree panoramas taken during the fall visit to the Traleika Index Station in 2008 and 2009.

Muldrow Glacier Movement Site Panoramas

Fall 2006

Fall 2008

Fall 2009

Figure A-15. Comparison of 360 degree panoramas taken during the fall visit to the Muldrow Monument 2 in 2006, 2008, and 2009. This is the same area as Figure A-3 above but with a different area as the center of the photo.

Muldrow Glacier Movement Site near McGonagall Pass Panoramas

Fall 2005

Fall 2006

Fall 2008

Figure A-16. Comparison of 360 degree panoramas taken during the fall visit to the Muldrow Monument 1 in 2005, 2008, and 2009.

Figure A-17. A comparison photograph of the upper-mid Muldrow Glacier and small glaciers mantling Mt. Tatum.

From Muldrow Glacier, DENA, B. Washburn, 08/15/1949

From Muldrow Glacier, DENA, G. Adema, 08/21/2006
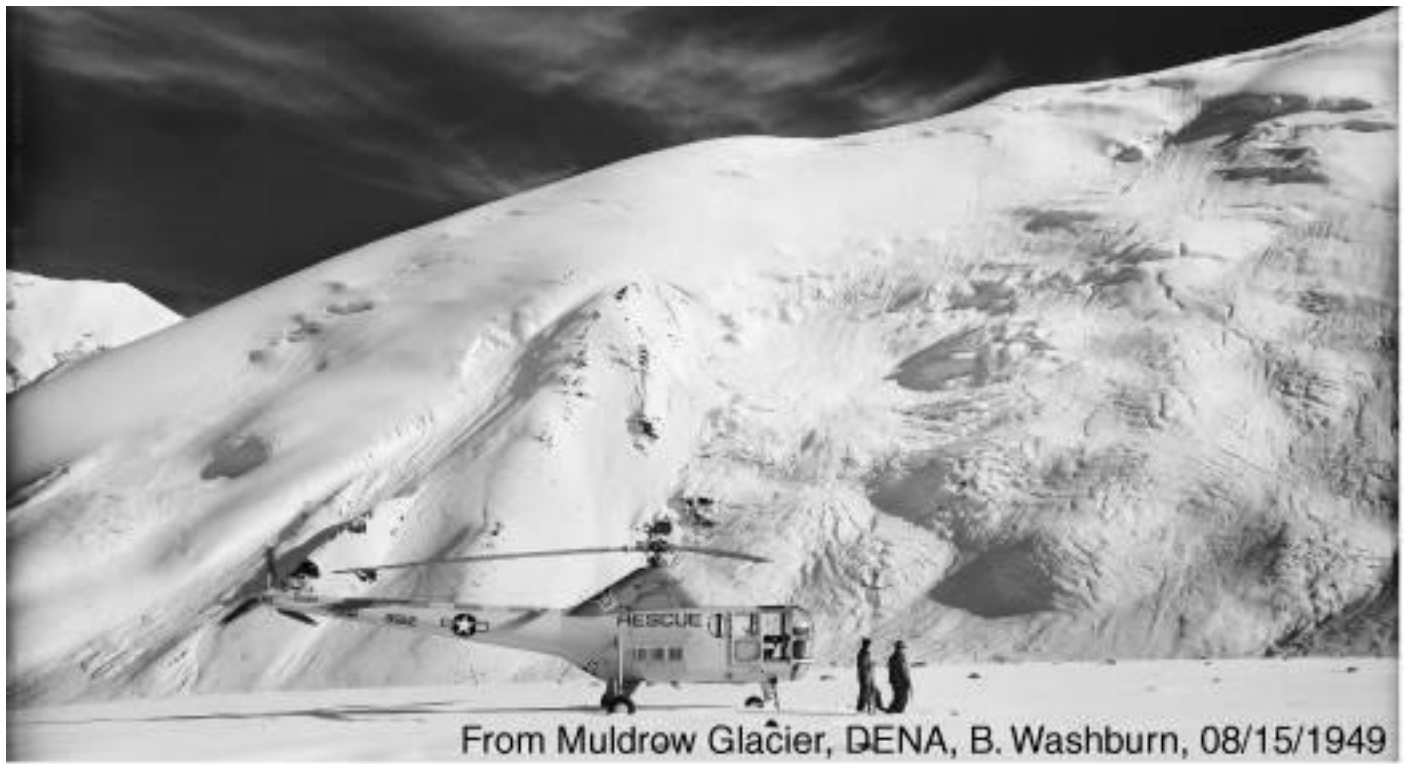
Figure A-18. A different perspective of some of the same terrain in Figure A-17.

Figure A-19. Aerial oblique photographs looking down the lower Muldrow Glacier to the terminus. The 1959 photo was soon after the 1956/57 surge.

Appendix B – East Fork Toklat Glacier GPS Survey data

Table B-1. All data were collected using two Trimble R6 GPS receivers, one as a base station at Point Natasha and the other as a rover. Coordinates are in WGS84 datum ellipsoid heights.

Pt_Name	Latitude	Longitude	height_m	height_ft
unamed_Pt	63.40016165	-149.6855883	2052.159	6731.1
97-10-6M	63.4108323	-149.681117	1783.936	5851.3
97-11-3M	63.40706709	-149.6844233	1873.293	6144.4
97-7-3m	63.41854343	-149.6687207	1686.636	5532.2
97-9E-3M	63.41259185	-149.6754518	1750.243	5740.8
dwnedunlbled	63.43060661	-149.6698891	1484.852	4870.3
eftaaab	63.43606978	-149.6721623	1422.418	4665.5
eftaice-2010	63.44526733	-149.6732029	1323.793	4342
eftammrne2010	63.44534233	-149.6746351	1355.558	4446.2
eftb-2010	63.42340633	-149.6656397	1612.316	5288.4
eftba-2010	63.42534771	-149.6653546	1586.614	5204.1
eftbaa2010	63.42788167	-149.6659017	1538.339	5045.8
eftbaaa2010	63.43028138	-149.6681576	1492.593	4895.7
eftc2010	63.41415707	-149.6735542	1732.814	5683.6
eftcb	63.41556901	-149.6716792	1719.819	5641
eftdddde	63.40682624	-149.6823688	1860.734	6103.2
eftddddee	63.40967849	-149.6811835	1796.909	5893.9
eftdddde	63.40484246	-149.6810851	1922.687	6306.4
eftdde	63.40363293	-149.680487	1956.311	6416.7
eftde	63.40301949	-149.681084	1968.443	6456.5
efte1	63.40039954	-149.6838787	2013.676	6604.9
efte2	63.4003454	-149.6825681	2006.705	6582
efte3	63.40021643	-149.6828134	2007.015	6583
eftterm01	63.4560169	-149.677269	1208.385	3963.5
eftterm06	63.45622465	-149.6766265	1208.747	3964.7
eftterm11	63.45608469	-149.6758275	1210.067	3969
eftterm16	63.4558062	-149.6749479	1210.82	3971.5
eftterm21	63.45485896	-149.6738711	1212.829	3978.1
natasha	63.46714367	-149.6847955	1364.494	4475.5
nrtrmonmmrne	63.45110064	-149.6749572	1284.94	4214.6
ScrwD	63.39979277	-149.6829731	2012.737	6601.8
toprebar	63.39977973	-149.682892	2011.526	6597.8
unabelledstk	63.42562342	-149.6648517	1581.172	5186.2

Table B-2. The baseline processing report output from the Trimble Business Office software after post processing the data. Most useful in this table are the horizontal and vertical precisions for each point.

Observation	From	To	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	DHeight (Meter)
natasha --- ? (B17)	natasha	?	Fixed	0.014	0.030	180°18'15"	7466.491	687.665
efte1 (B1)	natasha	efte1	Fixed	0.028	0.090	179°38'50"	7440.010	649.181
efte2 (B2)	natasha	efte2	Fixed	0.033	0.071	179°08'36"	7446.734	642.211
efte3 (B3)	natasha	efte3	Fixed	0.023	0.051	179°14'21"	7460.936	642.521
toprebar (B4)	natasha	toprebar	Fixed	0.026	0.047	179°16'27"	7509.559	647.031
ScrwD (B5)	natasha	ScrwD	Fixed	0.026	0.043	179°18'18"	7508.055	648.243
eftde (B6)	natasha	eftde	Fixed	0.028	0.038	178°30'49"	7150.229	603.949
eftdde (B7)	natasha	eftdde	Fixed	0.034	0.045	178°15'29"	7082.715	591.817
eftdddde (B8)	natasha	eftdddde	Fixed	0.036	0.044	178°28'14"	6947.094	558.192
97-11-3M (B9)	natasha	97-11-3M	Fixed	0.039	0.043	179°50'27"	6696.676	508.798
eftddddde (B10)	natasha	eftddddde	Fixed	0.044	0.051	178°58'00"	6724.588	496.240
2:33:07 PM - 2:34:17 PM (C1)	natasha	2:33:07 PM - 2:34:17 PM (C1)	N/A	?	?	?	?	?
2:34:30 PM - 2:34:33 PM (C2)	natasha	2:34:30 PM - 2:34:33 PM (C2)	N/A	?	?	?	?	?
2:34:43 PM - 2:42:46 PM (C3)	natasha	2:34:43 PM - 2:42:46 PM (C3)	N/A	?	?	?	?	?
eftdddddee (B11) ⚑	natasha	eftdddddee	Fixed	0.061	0.085	178°23'11"	6408.099	432.415
2:52:14 PM - 2:54:50 PM (C4)	natasha	2:52:14 PM - 2:54:50 PM (C4)	N/A	?	?	?	?	?
97-10-6M (B12)	natasha	97-10-6M	Fixed	0.018	0.027	178°19'23"	6279.634	419.441
3:17:28 PM - 3:25:15 PM (C5)	natasha	3:17:28 PM - 3:25:15 PM (C5)	N/A	?	?	?	?	?
97-9E-3M (B13)	natasha	97-9E-3M	Fixed	0.026	0.039	175°36'37"	6098.671	385.748
3:31:21 PM - 3:37:29 PM (C6)	natasha	3:31:21 PM - 3:37:29 PM (C6)	N/A	?	?	?	?	?
eftc2010 (B14)	natasha	eftc2010	Fixed	0.033	0.054	174°34'08"	5932.928	368.319
3:41:32 PM - 3:43:17 PM (C7)	natasha	3:41:32 PM - 3:43:17 PM (C7)	N/A	?	?	?	?	?
eftcb (B15)	natasha	eftcb	Fixed	0.027	0.047	173°29'54"	5786.103	355.325
3:58:29 PM - 4:04:34 PM (C8)	natasha	3:58:29 PM - 4:04:34 PM (C8)	N/A	?	?	?	?	?
97-7-3m (B16)	natasha	97-7-3m	Float	0.041	0.058	171°34'11"	5476.474	322.142
eftb-2010 (B18)	natasha	eftb-2010	Fixed	0.023	0.046	168°53'55"	4968.164	247.821
eftba-2010 (B19)	natasha	eftba-2010	Fixed	0.024	0.048	168°13'46"	4758.860	222.120
unabelledstk (B20)	natasha	unabelledstk	Fixed	0.020	0.040	167°51'22"	4733.987	216.677
eftbaa2010 (B21)	natasha	eftbaa2010	Fixed	0.020	0.034	167°50'08"	4476.867	173.844
eftbaaa2010 (B22)	natasha	eftbaaa2010	Fixed	0.017	0.030	168°34'16"	4192.008	128.098
dwnedunlbled (B23)	natasha	dwnedunlbled	Fixed	0.016	0.025	169°38'40"	4140.090	120.357
eftaaab (B24)	natasha	eftaaab	Fixed	0.015	0.026	169°40'55"	3520.641	57.923
eftaice-2010 (B25)	natasha	eftaice-2010	Fixed	0.013	0.025	166°39'17"	2506.152	-40.702
eftammrne2010 (B26) ⚑	natasha	eftammrne2010	Float	0.249	0.489	168°12'56"	2482.455	-8.937
nrtrmonmmrne (B32)	natasha	nrtrmonmmrne	Fixed	0.010	0.019	164°39'07"	1854.398	-79.555
eftterm01 (B27)	natasha	eftterm01	Fixed	0.010	0.014	163°09'33"	1295.842	-156.109
eftterm06 (B28)	natasha	eftterm06	Fixed	0.016	0.023	161°29'24"	1283.503	-155.747
eftterm11 (B29)	natasha	eftterm11	Fixed	0.016	0.025	160°03'17"	1311.357	-154.427
eftterm16 (B30)	natasha	eftterm16	Fixed	0.016	0.026	158°45'32"	1355.848	-153.674
eftterm21 (B31)	natasha	eftterm21	Fixed	0.015	0.023	158°17'57"	1473.768	-151.666

Glacier Monitoring Observations (Page 1: Data Form)
U.S. Department of the Interior, Denali National Park

Date: 9/21/2010   Observer(s): R. Burrows, A. Ackerman
Site Name (circle one):   Kahiltna   Traleika   SE Fork Upper   SE Fork Lower
(EFT)

BASIC OBSERVATIONS

1. Balance Pole:

    a) Stake Name (i.e. 98-K17-12M): **97-7-3M**
        a') Total stake length (from stake name): 3.00 m
    b) Height of exposed portion of stake: 1.26 m
    c) Surface Height on Stake (= a' – b): _____ m
    d) Is stake: Bent   Leaning   Bowed ?
    e) If bent, relative to the top of the stake where is the bend? _____ m

2. Surface Strata: (circle one): Snow Glacier Ice   Superimposed Ice

        New Firn   Old Firn   Superfirn

    Describe other observations (e.g. Is there fresh snow? How much? etc):
    A of the top sections were broken
    apart and laying on ice.

Figure B-1. The top of the datasheet for stake 97-7-3M on the East Fork Toklat Glacier (EFT). The GPS data was not recorded on this sheet thus the bottom section is not included in the interest of space.

Glacier Monitoring Observations (Page 1: Data Form)
U.S. Department of the Interior, Denali National Park

Date: 9/21/2010   Observer(s): R. Burrows, A. Ackerman
Site Name (circle one):   Kahiltna   Traleika   SE Fork Upper   SE Fork Lower
(EFT)

BASIC OBSERVATIONS

1. Balance Pole:

    a) Stake Name (i.e. 98-K17-12M): **97-9E-3M**
        a') Total stake length (from stake name): 3.00 m
    b) Height of exposed portion of stake: 2.36 m
    c) Surface Height on Stake (= a' – b): _____ m
    d) Is stake: Bent   Leaning   Bowed ?
    e) If bent, relative to the top of the stake where is the bend? _____ m

2. Surface Strata: (circle one): Snow Glacier Ice   Superimposed Ice

        New Firn   Old Firn   Superfirn

    Describe other observations (e.g. Is there fresh snow? How much? etc):

Figure B-22. The top of the datasheet for stake 97-9E-3M on the East Fork Toklat Glacier (EFT). The GPS data was not recorded on this sheet thus the bottom section is not included in the interest of space.

Glacier Monitoring Observations (Page 1: Data Form)
U.S. Department of the Interior, Denali National Park

Date: 9/21/2010   Observer(s): V. Purimus , A. Ackerman
Site Name (circle one):   Kahiltna   Traleika   SE Fork Upper   SE Fork Lower
                                    (EFT)

BASIC OBSERVATIONS

1. Balance Pole:

    a) Stake Name (i.e. 98-K17-12M):   97-10-6M
        a') Total stake length (from stake name):   6.00 m
    b) Height of exposed portion of stake: 1.24 m
    c) Surface Height on Stake (= a' – b):   _____ m
    d) Is stake: Bent   Leaning   Bowed ?
    e) If bent, relative to the top of the stake where is the bend? _____ m
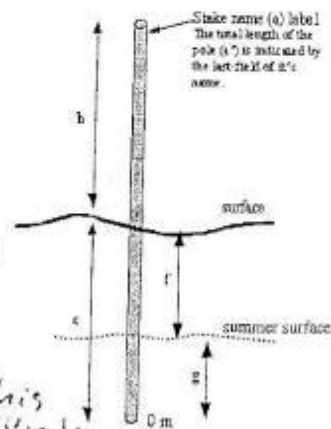
2. Surface Strata: (circle one): Snow Glacier Ice   Superimposed Ice

                New Firn   Old Firn   Superfirn

Describe other observations (e.g. Is there fresh snow? How much? etc):

Note: Handheld GPS battery died. Significant superimposed ice in this area. Started up-glacier below old firn line

3. Snow Pit: (dug 5-10 meters from stake)

    f) Depth to last summer's surface from present surface: _____ m
    g) Height of summer surface on stake: _____ m (= c - f)
    h) Average Snow Density:

	Depth	Length	Weight	Tare
Sample 1				
Sample 2				
Sample 3				

4. Snow Probing: (5-10 measurements)

_____ _____ _____ _____ _____ _____ _____ _____

    i) Average _____ m (f and i should be similar)

5. Hobo
        Off #:   Time:
        On #:   Time:

GPS DATA On the back of this sheet describe GPS survey configuration including base station used.

Note: And height recorded @ 1.60 but should be 0.77m

	Field Data		Post Processing Data

Figure B-33. The top of the datasheet for stake 97-10-6M on the East Fork Toklat Glacier (EFT). The GPS data was not recorded on this sheet thus the bottom section is not included in the interest of space.

Glacier Monitoring Observations (Page 1: Data Form)
U.S. Department of the Interior, Denali National Park

Date: 9/31/2010   Observer(s): R. Burrows, A. Ackerman

Site Name (circle one):   Kahiltna   Traleika   SE Fork Upper   SE Fork Lower
                              EF Toklat

BASIC OBSERVATIONS

1. Balance Pole:

a) Stake Name (i.e. 98-K17-12M):   97-11-3M
   a') Total stake length (from stake name): _____ 3.00 m
b) Height of exposed portion of stake: _____ 2.16 m
c) Surface Height on Stake (= a' – b): _____ m
d) Is stake: Bent   Leaning   Bowed ?
e) If bent, relative to the top of the stake where is the bend? _____ m

2. Surface Strata: (circle one): Snow   Glacier Ice   Superimposed Ice

New Firn   Old Firn   Superfirn

Describe other observations (e.g. Is there fresh snow? How much? etc):

Stake name (a) label
The total length of the
pole (a') is indicated by
the last-field of a's
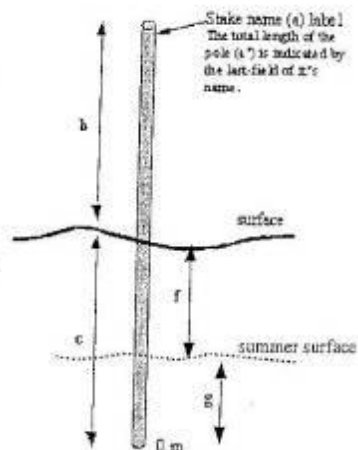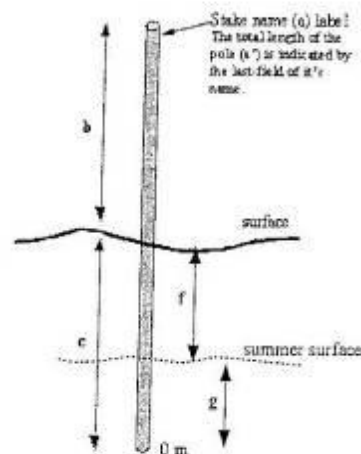name.

surface

summer surface

0 m
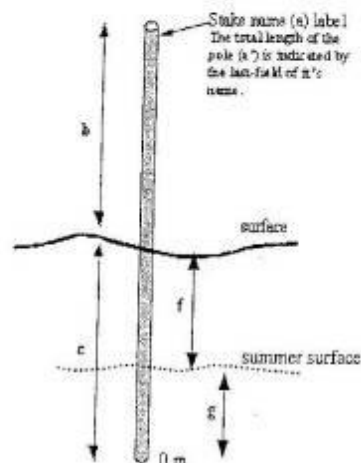
Figure B-4. The top of the datasheet for stake 97-11-3M on the East Fork Toklat Glacier (EFT). The GPS data was not recorded on this sheet thus the bottom section is not included in the interest of space.

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Appendix C – 2010 Index Data

Table C-1. Balance Data from the worksheet used to calculate the balances from the data collected in the field.

Color Key:

(maroon)	Indicates results
(green)	Raw data input
(gray)	Misc Info
(purple)	Data linked to or calculated in other sheets
No Color	Data calculated in this sheet
(light gray)	Input Columns for GPS methods
(lavender)	Data calculation for GPS methods

Summary Data

							OBSERVATIONS								SURFACE MASS BALANCES					
Glacier	Stake Name	Date	Tape b'	Survey b^*	Survey b^{**}	Strata	Pit d	Probe d	Average d	s.e.	n	Summer Surf. Obsvd. b'_{ss}	Density ρ	Stake $b'(i)$	Ice $b_a(i)$	Depth d	Density ρ	Estimated or Measured	"Snow" $b_n(f)$	Seasonal Balance bw & bs	Net Balance b_n	Cumulative Balance b_a
		m/d/y	m	m	m		m	m	m	m		m	kg/L	m(w)	m(w)	m	kg/L		m(w)	m(w)	m(w)	m(w)
Kahiltna	07-K17-9M	05/19/10	7.53			Snow	1.68		1.74		10	5.85				1.74	0.36	Measured	0.63	0.63		
	07-K17-9M	09/14/10	5.32			Old firn						5.32	0.80	4.26	-0.41	0.00				-1.03	-0.41	3.00
	K17-10-6M	09/15/10	3.60			Old firn						3.60	0.80	4.26								
Traleika	07-T-6M	05/18/10	6.17			Snow	1.35		1.28		10	4.82	0.90	4.34	-0.25	1.28	0.41	Measured	0.53	0.53		
	07-T-6M	09/12/10	3.42			Ice						3.42	0.90	3.08	-1.26					-2.04	-1.51	-13.26
	T-10-7M	09/15/10	4.92			Ice						4.92	0.90	4.43								

Table C-2. Ice motion and glacier surface height data from the long-term observation sites.

[X, Y, and Z, coordinates of stake base; V, displacement speed; b', stake reading, height of surface above base of stake; e, emergence, the amount the glacier would have thickened had the balance been zero; and V_e, emergence rate.]

Date (mm/dd/yyyy)	Period - (fraction of a year)	X (m)	Coordinates Y (m)	Z (m)	Speed V (m/yr)	Direction Horizontal (grad)	Vertical (grad)	Surface Altitude (m)	Snow Depth (m)	SSurf. Altitude (m)	Stake b' (m)	Emergence e (m)	Ve (m/yr)
		Kahiltna	STAKE 07-K17-9M										
8/20/2007											6.49		
9/1/2008	1.035	588,999.9	6,980,040.3	1935.203		94.641	0.018	1935.203	0.00	1935.203	6.93		
5/24/2009	0.726	589,008.7	6,979,889.8	1933.685	208	-96.281	-0.641	1933.685	2.23	1931.460	8.85	-3.44	-4.74
9/3/2009	0.279	589,011.8	6,979,843.4	1929.961	167	-95.764	-5.087	1929.961	0.00	1929.961	6.15	-1.02	-3.67
5/19/2010	0.706	589,022.5	6,979,712.5	1928.146	186	-94.800	-0.880	1928.146	1.74	1926.402	7.53	-3.20	-4.52
9/14/2010	0.323	589,011.0	6,979,650.8	1924.395	195	-111.765	-3.801	1924.395	0.00	1924.395	5.32	-1.54	-4.77
		Traleika	STAKE 07-T-9M										
8/20/2007											6.78		
6/1/2008	0.783								1.37		7.48		
9/1/2008	0.252	611,380.29	7,001,637.60	2088.0270		94.455	0.019	2088.0270	0.00	2088.027	6.39		
5/25/2009	0.728	611,385.46	7,001,672.14	2088.2980	48	90.551	0.494	2088.2980	0.87	2087.432	7.19	-0.53	-0.73
9/1/2009	0.271	611,388.94	7,001,699.46	2085.8710	102	91.920	-5.596	2085.8710	0.00	2085.871	5.30	-0.54	-1.98
5/18/2010	0.709	611,396.26	7,001,767.27	2084.7720	96	93.158	-1.026	2084.7720	1.28	2083.489	6.17	-1.97	-2.78
9/12/2010	0.320	611,407.51	7,001,812.89	2083.8730	147	84.608	-1.218	2083.8730	0.00	2083.873	3.42	1.85	5.78

Table C-3. Coordinates measured using GPS around the index station coordinate on Kahiltna and Traleika Glaciers for the spring and fall visits in 2010.

Glacier	Date	Point Name	X	Y	Z	Horizontal Error	Vertical Error	UTM Zone	Datum
Kahiltna	5/19/2010	S10Q	589,029.09	6,980,231.87	1938.54	0.02	0.03	5	WGS84
	5/19/2010	S10R	589,003.82	6,980,233.40	1938.36	0.01	0.01	5	WGS84
	5/19/2010	S10S	589,024.27	6,980,251.21	1938.99	0.01	0.01	5	WGS84
	9/14/2010	F10Q	589,020.10	6,980,285.68	1937.53	0.01	0.02	5	WGS84
	9/14/2010	F10R	588,933.55	6,980,260.52	1936.87	0.01	0.01	5	WGS84
	9/14/2010	F10S	588,960.34	6,980,175.60	1934.82	0.23	0.19	5	WGS84
Traleika	5/18/2010	S10Q	611,653.83	7,001,651.61	2103.46	0.01	0.02	5	WGS84
	5/18/2010	S10R	611,679.98	7,001,786.43	2095.06	0.01	0.01	5	WGS84
	5/18/2010	S10S	611,742.79	7,001,721.41	2096.16	0.01	0.01	5	WGS84
	9/12/2010	F10Q	611,680.44	7,001,783.17	2095.22	0.01	0.01	5	WGS84
	9/12/2010	F10R	611,790.95	7,001,759.30	2091.79	0.01	0.01	5	WGS84
	9/12/2010	F10S	611,728.13	7,001,651.20	2101.29	0.00	0.01	5	WGS84

Glacier Monitoring Observations (Page 1: Data Form)
U.S. Department of the Interior, Denali National Park

Date: **5/19/10**   Observer(s): **Burrows, Toubman**
Site Name (circle one): (**Kahiltna**)   Traleika   SE Fork Upper   SE Fork Lower

BASIC OBSERVATIONS

1. Balance Pole:

a) Stake Name (i.e. 98-K:7-12M): **K17-07 9M**
   a') Total stake length (from stake name): **9 M** m
b) Height of exposed portion of stake: **1.47** m
c) Surface Height on Stake (= a' – b). **7.63** m
d) Is stake: Bent   Leaning   Bowed ?
e) If bent, relative to the top of the stake where is the bend? _____ m
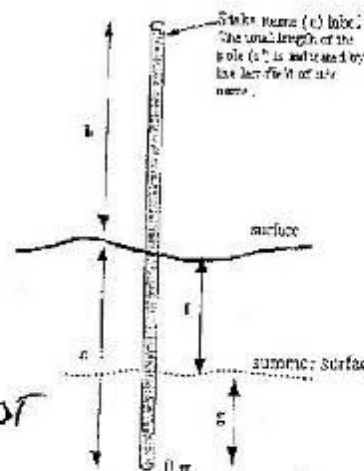
2. Surface Strata: (circle one) (**Snow**) Glacier Ice   Superimposed Ice

New Firn   Old Firn   Superfirn

Describe other observations (e.g. Is there fresh snow? How much? etc):

**antenna height in GPS point KBOT
is wrong should be 0.0**

3. Snow Pit: (dug 5-10 meters from stake)

— No pit, just probes & core. Core sampled vertically.

f) Depth to last summer's surface from present surface: **1.68** m depth @ stake
g) Height of summer surface on stake. _____ m (= c – f)
h) Average Snow Density:

Use Depth (in)

p (kg m³)		Depth	kg/m³	Weight	Tare	Whatever snow that was
0.81	Sample 1	**1.3 m ≠ 51.2**		**41.0**	**30.5**	retained in given core
0.36	Sample 2	**1.45 m ≠ 57.1**		**51.2**	1"	was weighed and the
0.81	Sample 3	**1.18 m ≠ 46.5**		**44.0**	"	depth measured in the hole with a tape/probe

Use this value say since it best samples close to no entire snowpack depth

4. Snow Probing: (5-10 measurements) **thrand out, in crevasse**

1.65   2.75   1.70   1.64   1.60   1.9   1.75   1.85   1.85   1.75   1.75

i) Average _____ m (f and i should be similar)

5. Hobo

Off #: _____   Time: _____
On #: _____   Time: _____

GPS DATA On the back of this sheet describe GPS survey configuration including base station used.

Target	GPS/Card	Time	Northing (Field Data)	Easting	HAE (m) (Post Processing Data)	Hz Err (m)	Vt Err (m)
Stake Base	**KBOT**		**6979712.530**	**589072.485**	**1938.146**	**0.011**	**0.012**
Stake Top	**Not Measured**						
Q_surf	**KBAS**		**6980021.867**	**589029.026**	**1938.538**	**0.016**	**0.055**
R_surf	**KR**		**6980033.399**	**589002.834**	**1938.355**	**0.006**	**0.011**
S_surf	**KPAN**		**6983951.313**	**589024.365**	**1938.989**	**0.006**	**0.010**

Use WGS84 (NAD 83) datum!

Figure C-1. A copy of the working data sheet for the spring visit on 5/19/10 to the Kahiltna Index Station.

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Glacier Monitoring Observations (Page 1: Data Form)
U.S. Department of the Interior, Denali National Park

Date: 9/14/10

Observer(s): Rob Burrows

Site Name (circle one): (Kahiltna)   Traleika   SE Fork Upper   SE Fork Lower

BASIC OBSERVATIONS

1. Balance Pole:

a) Stake Name (i.e. 98-K17-12M): K17-07-9__
  a') Total stake length (from stake name): 9 m
b) Height of exposed portion of stake: 3.68 m
c) Surface Height on Stake (= a' – b): 5.32 m
d) Is stake: Bent   Leaning   Bowed ?
e) If bent, relative to the top of the stake where is the bend? _____ m

2. Surface Strata: (circle one): Snow Glacier Ice   Superimposed Ice

New Firn   Old Firn   Superfirn

Describe other observations (e.g. Is there fresh snow? How much? etc):

new snow 5-10cm

Stake name (e) label
The total length of the pole (a') is indicated by the last field of a's name.

surface

summer surface

0 m

3. Snow Pit: (dug 5-10 meters from stake)

f) Depth to last summer's surface from present surface: _____ m
g) Height of summer surface on stake: _____ m (= c - f)
h) Average Snow Density:

	Depth	Length	Weight	Tare
Sample 1				
Sample 2				
Sample 3				

4. Snow Probing: (5-10 measurements)

i) Average _____ m (f and i should be similar)

5. Hobo

Off #:   Time:
On #:   Time:

GPS DATA On the back of this sheet describe GPS survey configuration including base station used.

Panorama Kranfall   58901.881 6980205.722 1937.154 0.012 0.030

	Field Data		Post Processing Data					
Target	GPS/Card	Time	Easting (m)	Northing (m)	HAE (m)	Hz Err (m)	Vt Err (m)	
Stake Base	kotkfl10		589010955	6979650.845	1924.395	0.016	.017	These are
Stake Top	Not recorded							adjusted
Q surf	Use Kbase10 below							values
R surf	Kr		586933.546	6980260.512	1926.866	0.008	0.005	
S surf	Ksf10		588960.339	6770175.597	1934.715	0.226	0.189	Kb
Use WGS84 (NAD 83) datum!			589019.108	6980284.668	1977	TBC software adjusts this slightly, when
GPS Base station	Kbase10	USE THIS Adj	589020.096 +5.188	6980285.680 +1.015	1977.35 0.44	0.012	0.018	processing local baselines -I will adjust difference
			W151°14'45.7037" N62°46'31.42189"					

Glacier Monitoring Observations (Page 1: Data Form)
U.S. Department of the Interior, Denali National Park

Date: 5/18/10   Observer(s): Adema, Burrows

Site Name (circle one):   Kahiltna   (Traleika)   SE Fork Upper   SE Fork Lower

BASIC OBSERVATIONS

1. Balance Pole:

a) Stake Name (i.e. 98-K17-12M):   07-T-9M
a') Total stake length (from stake name):   9   m
b) Height of exposed portion of stake: 2.83   m
c) Surface Height on Stake (= a' – b):   6.62   m
d) Is stake: Bent   Leaning   Bowed ?
e) If bent, relative to the top of the stake where is the bend? ____ m
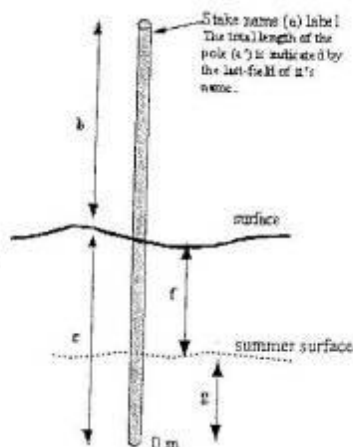
(handwritten margin note: 2.6, 2.6, 6.6)

2. Surface Strata: (circle one): (Snow) Glacier Ice   Superimposed Ice

                New Firn   Old Firn   Superfirn

Describe other observations (e.g. Is there fresh snow? How much? etc):

(diagram at right with labels: Stake name (a) label; The total length of the pole (a') is indicated by the last field of it's name; surface; summer surface; 0 m; b; f; e; g)

3. Snow Pit: (dug 5-10 meters from stake)

f) Depth to last summer's surface from present surface: ____ m
g) Height of summer surface on stake: ____ m (= c - f)
h) Average Snow Density

ρ		Depth	Length	Weight	Tare
0.47	Sample 1	25.5	19	25	13
0.37	Sample 2	27	23	30	20
0.39	Sample 3	33	33	33	23

Ave: 0.41

4. Snow Probing: (5-10 measurements)

135   138   140   130   110   113   111   134   135   137

i) Average ____ m (f and i should be similar)

5. Hobo

Off #:   Time:
On #:   Time:

GPS DATA On the back of this sheet describe GPS survey configuration including base station used.

tropaus   611619.960 7001624.4531 2110.208

Target	Name Field Data GPS Card			Post Processing Data			
			Easting (m)	Northing (m)	HAE (m)	Hz Err (m)	Vt Err (m)
Stake Base	TBOT	0.13	611398.259	7001767.268	2084.772	0.009	0.015
Stake Top	Not Measured						
Q surf	TBAS trabase 2		611653.832	7001651.607	2103.462	0.007 0.013	0.018
R surf	TR		611679.584	7001786.429	2095.057	0.006	0.007
S surf	TS		611742.788	7001791.413	2096.159	0.006	0.007
Use WGS84 (NAD 83) datum! on monument	mu 2		629421.816	7018359.321	1321.345	0.007 0.013	0.025
	mu 2pau		629371.586	7018297.403	1328.517	0.009	0.013

(margin note at right: determined with baseline to GRNX (days))

Figure C-3. A copy of the working data sheet for the spring visit on 5/18/10 to the Traleika Index Station.

Glacier Monitoring Observations (Page 1: Data Form)
U.S. Department of the Interior, Denali National Park

Date: 9/12/10   Observer(s): R. Burrows
Site Name (circle one):   Kahiltna   (Traleika)   SE Fork Upper   SE Fork Lower

BASIC OBSERVATIONS

1. Balance Pole:

Stake name (a) label — The total length of the pole (a') is indicated by the last field of it's name

6M top, is adjusted to...

a) Stake Name (i.e. 98-K17-12M): 07-T-9M
a') Total stake length (from stake name): 9 m
b) Height of exposed portion of stake: 3 + 258 = 5.58
c) Surface Height on Stake (= a' – b): 3.42 m
d) Is stake: Bent   (Leaning)   Bowed ?
e) If bent, relative to the top of the stake where is the bend? ___ *measured with compass inclinometer*
Stake severely leaning. 31° off vertical

2. Surface Strata: (circle one): (Snow) (Glacier Ice)   Superimposed Ice
new snow   New Firn   Old Firn   Superfirn
on glacia ice
Describe other observations (e.g. Is there fresh snow? How much? etc):

~3cm new snow
- Top section was cannabalized for new stake on 9/15/10

3. Snow Pit: (dug 5-10 meters from stake) None

f) Depth to last summer's surface from present surface: _____ m
g) Height of summer surface on stake: _____ m (= c – f)
h) Average Snow Density:

	Depth	Length	Weight	Tare
Sample 1				
Sample 2				
Sample 3				

4. Snow Probing: (5-10 measurements)

i) Average _____ m (f and i should be similar)

5. Hobo

Off #: _____   Time: _____
On #: _____   Time: _____

Diagram of measurements

3m

Top GPS measurement

2.58m

1.50m

ice surface

31°

3.42

sin 31 = x/3.42

x = 1.76

GPS DATA On the back of this sheet describe GPS survey configuration including base station used.

Target	GPS/Card	Time	Easting (m)	Northing (m)	HAE (m)	Hz Err (m)	Vt Err (m)
Stake Base	+bot		611407.509	7001812.888	2083.873	0.011	0.018
Stake Top	+top		611407.576	7001813.656	2083.787	0.005	0.009
Q_surf	+Q		611680.440	7001783.172	2095.217	0.007	0.013
R_surf	+R		611790.945	7001759.303	2091.785	0.005	0.008
S_surf	+S		611728.134	7001651.195	2101.289	0.003	0.006
base station	trabase 2010		611617.954	7001607.926	2110.972	0.018	0.051

Use WGS84 (NAD 83) datum!
W150°47'11.37150" N63°07'35.42453"

Figure C-4. A copy of the working data sheet for the fall visit on 9/12/10 to the Traleika Index Station.

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Glacier Monitoring Observations (Page 1: Data Form)
U.S. Department of the Interior, Denali National Park

Date: **9/15/10**　　　　　　　Observer(s): **R. Burrows**

Site Name (circle one):　Kahiltna　　(Traleika)　　SE Fork Upper　　　SE Fork Lower

BASIC OBSERVATIONS

1. Balance Pole:

a) Stake Name (i.e. 98-K17-12M): **T-10-7M**
　　a') Total stake length (from stake name): **7.00 m**
b) Height of exposed portion of stake: **2.08 m**
c) Surface Height on Stake (= a' – b): **4.92 m**
d) Is stake:　　　　Bent　　　Leaning　　　Bowed ?
e) If bent, relative to the top of the stake where is the bend? _____ m
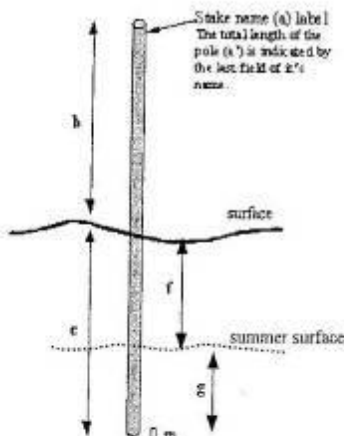
2. Surface Strata: (circle one): Snow　(Glacier Ice)　　Superimposed Ice

　　　　　　　　New Firn　　　Old Firn　　　Superfirn

Describe other observations (e.g. Is there fresh snow? How much? etc):

- 3-5 cm new snow
- new stake placed on this date
- stake made of 1 section of 3m and
　2 uppers sections of 2m

3. Snow Pit: (dug 5-10 meters from stake)

f) Depth to last summer's surface from present surface: _____ m
g) Height of summer surface on stake: _____ m (= c - f)
h) Average Snow Density:

	Depth	Length	Weight	Tare
Sample 1				
Sample 2				
Sample 3				

4. Snow Probing: (5-10 measurements)

i) Average _____ m (f and i should be similar)

5. Hobo

Off #:　　　　Time:
On #:　　　　Time:

GPS DATA On the back of this sheet describe GPS survey configuration including base station used.

	Field Data		Post Processing Data				
Target	GPS/Card	Time	Easting (m)	Northing (m)	HAE (m)	Hz Err (m)	Vt Err (m)
Stake Base							
Stake Top							
Q_surf							
R_surf							
S_surf							

Use WGS84 (NAD 83) datum!

GPS base station　tbse 091510 + tstk10bs　611302.612　7001550.15　3010.910　0.020　0.029

W150°47'34.00513"　N63°07'33.91113"

Tark 2 base measurements @ same location 1 for last stake will get ppk

Figure C-5. A copy of the working data sheet for the visit on 9/15/10 to the Traleika Index Station to place a new ablation stake.

Glacier Monitoring Observations (Page 1: Data Form)
U.S. Department of the Interior, Denali National Park

Date: **9/15/10**   Observer(s): **R. Burrows**

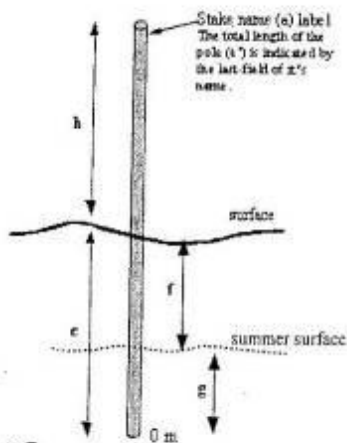Site Name (circle one): (**Kahiltna**)   Traleika   SE Fork Upper   SE Fork Lower

BASIC OBSERVATIONS

1. Balance Pole:

   a) Stake Name (i.e. 98-K17-12M): **K17-10-6M**
   a') Total stake length (from stake name): **6** m
   b) Height of exposed portion of stake: **7.40** m
   c) Surface Height on Stake (= a' – b): **4.60** m
   d) Is stake: Bent   Leaning   Bowed ?
   e) If bent, relative to the top of the stake where is the bend? _____ m

   Stake name (a) label — The total length of the pole (a') is indicated by the last field of a's name.

   h
   surface
   f
   e   *summer surface*
   g
   0 m

2. Surface Strata: (circle one): Snow   Glacier Ice   Superimposed Ice

   New Firn   (Old Firn)   Superfirn

   Describe other observations (e.g. Is there fresh snow? How much? etc):

   — 5–10 cm of new snow
   — New stake placed on this date
   — stake made of 3 2-meter sections

3. Snow Pit: (dug 5-10 meters from stake)

   f) Depth to last summer's surface from present surface: _____ m
   g) Height of summer surface on stake: _____ m (= e - f)
   h) Average Snow Density:

	Depth	Length	Weight	Tare
Sample 1				
Sample 2				
Sample 3				

4. Snow Probing: (5-10 measurements)

   _____ _____ _____ _____ _____ _____

   i) Average _____ m (f and i should be similar)

5. Hobo
   Off #:   Time:
   On #:   Time:

GPS DATA On the back of this sheet describe GPS survey configuration including base station used.

Target	Field Data			Post Processing Data			Hz Err (m)	Vt Err (m)
	GPS/Card	Time	Easting (m)					
Stake Bot	K17 10 6m			Need to recheck			.009	0.016
~~Stake Top~~	Lat Lon	→	W150°5'12.???	base station				
Q_surf				coords. + do				
R_surf				for 9/15 surveys				
S_surf								

Use WGS84 (NAD 83) datum!

Base station K17nwstkbase /588907.073 6981123.330 1942.5?3 0.480 m 0.194 m
Kbase 2 /W151°14'51.57??? N62°56'56.57425

Need to recheck base station coords. + do for 9/15 surveys

In the future may not necessary to broke stake out if new stake

Took 2 base measurements @ same location 1 for fast static 1 for PPK

Figure C-6. A copy of the working data sheet for the visit on 9/15/10 to the Kahiltna Index Station to place a new ablation stake.

Appendix D- Index Data Summary

Table D-1. A summary of balances for the entire period of record for Kahiltna and Traleika Glaciers.

Kahiltna

Balance Year	Balances bw	bs	bn	bn Cumulative	Percent of Average bw	bs	normalized deviation from average bn
1991	1.23	-0.46	0.77	0.77	114	48	63
1992	1.15	-1.74	-0.59	0.18	106	182	-64
1993	1.15	-0.74	0.41	0.59	107	77	30
1994	2.00	-0.84	1.16	1.76	186	88	100
1995	0.57	-1.02	-0.48	1.27	53	107	-54
1996	1.05	-0.52	0.45	1.72	98	54	33
1997	0.98	-1.33	-0.35	1.37	91	140	-42
1998	1.07	-0.30	0.77	2.14	99	31	63
1999	0.81	-1.77	-0.97	1.17	75	186	-100
2000	No data	No data	0.97	2.14	No data	No data	82
2001	1.32	-1.32	0.00	2.14	122	138	-9
2002	0.84	-0.63	0.21	2.35	77	66	11
2003	1.09	-0.31	0.78	3.13	101	33	65
2004	0.91	-1.55	-0.64	2.50	84	162	-69
2005	1.20	-1.30	-0.10	2.40	111	136	-18
2006	0.90	-0.95	-0.05	2.35	84	100	-13
2007	No data	No data	0.35	2.70	No data	No data	24
2008	No data	No data	0.21	2.90	No data	No data	11
2009	1.00	-0.50	0.50	3.41	93	52	39
2010	0.63	-1.03	-0.41	3.00	58	108	-47
Averages	1.08	-0.95	0.18				
Maximum	2.00	-0.30	1.16				
Minimum	0.57	-1.77	-0.97				

Tralieka

bal. yr	bw	bs	bn	bn Cumulative	Percent of Average bw	bs	normalized deviation from average bn
1991	0.58	-1.09	-0.51	-0.51	87	83	35
1992	0.88	-1.35	-0.41	-0.92	132	103	45
1993	0.78	-1.00	-0.22	-1.14	117	76	65
1994	1.00	-1.60	-0.60	-1.74	150	122	26
1995	0.95	-1.16	-0.21	-1.95	142	88	65
1996	0.35	-1.22	-0.80	-2.75	52	93	6
1997	0.47	-1.57	-1.09	-3.84	71	119	-23
1998	0.40	-0.26	0.14	-3.70	60	20	100
1999	0.60	-1.96	-1.36	-5.06	90	149	-51
2000	No Data	No Data	-0.22	-5.29	No Data	No Data	64
2001	0.57	-0.57	0.00	-5.29	86	43	86
2002	0.60	-1.44	-0.84	-6.12	91	110	2
2003	0.90	-0.78	0.13	-6.00	136	59	99
2004	0.42	-2.27	-1.85	-7.84	63	172	-100
2005	1.15	-2.68	-1.53	-9.37	173	204	-68
2006	0.73	-1.34	-0.61	-9.98	110	102	25
2007	0.65	-1.31	-0.66	-10.64	98	99	20
2008	0.58	-0.53	0.05	-10.59	88	40	92
2009	0.37	-1.53	-1.16	-11.75	56	116	-31
2010	0.53	-2.04	-1.51	-13.26	79	155	-66
Averages	0.67	-1.31	-0.62				
Maximum	1.15	-0.26	0.14				
Minimum	0.35	-2.68	-1.85				

Equilibrium Line Altitudes		
Year	Kahiltna	Tralieka
1991	1690	2140
1992	2200	2100
1993	1830	2090
1994	1690	2160
1995	2140	2090
1996	1790	2360
1997	2040	2290
1998	1753	2029
1999	2300	2359
2000	1719	2115
2001	1920	2070
2002	1854	2255
2003	1754	2049
2004	2281	2481
2005	1965	2416
2006	1944	2220
2007	1836	2234
2008	1874	2082
2009	1800	2350
2010	2104	2425
Average	**1924**	**2216**
Maximum	2300	2481
Minimum	1690	2029

Table D-2. A summary of the calculated ELAs for the Index glaciers. ELAs for 1992 through 1995 were calculated using two stakes. For other years the ELA is calculated using an assumed balance gradient, the altitude of the stake and the net balance for that year (see equation 6 in the main report).

Table D-3. A summary of the calculated net balances at the ELAs in Table D-2 for the Index glaciers in the main report. See equation 7 in the main report.

Net Balances at the Long-term ELAs				Cumulative bn	
Year	Kahiltna bn	Tralieka bn		Kahiltna	Traleika
1991	0.75	0.33		0.75	0.33
1992	-0.59	0.69		0.16	1.01
1993	0.40	0.59		0.56	1.60
1994	1.15	0.26		1.71	1.86
1995	-0.49	0.58		1.22	2.44
1996	0.43	-0.38		1.65	2.06
1997	-0.36	-0.35		1.29	1.71
1998	0.75	0.86		2.04	2.57
1999	-0.97	-0.66		1.07	1.91
2000	0.97	0.46		2.04	2.38
2001	0.01	0.67		2.05	3.05
2002	0.23	-0.18		2.29	2.86
2003	0.76	0.77		3.04	3.63
2004	-0.68	-1.22		2.37	2.41
2005	-0.12	-0.92		2.25	1.49
2006	-0.06	-0.02		2.19	1.47
2007	0.32	-0.08		2.51	1.38
2008	0.17	0.61		2.68	2.00
2009	0.49	-0.62		3.17	1.38
2010	-0.41	-0.96		2.76	0.42

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Appendix E– Report for CAKN 2010 Program Highlights

- Cooperative agreements were established with University of Alaska, Fairbanks and Alaska Pacific University to create glacier extent, inventory, and volume change products for Alaska national parks (including DENA and WRST) over the next 3 years.

- Development of a modern protocol document and standard operating procedures.

- Fieldwork was conducted at DENA during two field campaigns in May and September, in addition to a fixed wing over flight in March to search for surging glaciers. No surging glaciers were detected this year. Field measurements indicate that the net balance at both index stations and for the entirety of the glaciers was negative this year. The negative mass balance adds to the overall negative trend in the cumulative balance since measurements started in 1991. Although this year marks the reversal of a shorter term positive trend since 2004 on both glaciers. The surface speed at the index station appears to be decreasing through time since 1991 on Kahiltna and increasing at Traleika with an unprecedented acceleration between May and September 2010. Panoramic gigapixel photography was newly employed this year for several sites. In addition, a GPS survey on East Fork Toklat glacier collected glacier surface elevation data along a longitudinal profile, legacy mass balance stake location and heights, and several points to map the terminus position. The survey on East Fork Toklat shows continued thinning of 30 to 140 meters.

- Glacier monitoring program highlights and results were presented at the Northwest Glaciologists meeting in Fairbanks, AK on October 8, 2010.

Appendix F – Report for DENA Current Resource Projects

Long-term Glacier Monitoring

In 1991, Denali researchers established long-term glacier monitoring sites
on the Traleika and Kahiltna Glaciers to monitor long-term glacier flow and mass balance
changes. These glaciers were selected to compare glaciers on the north (Traleika) and south
(Kahiltna) sides of the Alaska Range (dryer and wetter climates, respectively). The measuring sites for
both glaciers are located at approximately 6000' (1830 m). The Kahiltna Glacier flows ~660 feet (200
meters) per year, while the Traleika Glacier moves ~230 feet (70 m) per year.

This was a busy year for the program with production of a modern protocol document with
several additions and changes to the monitoring protocol, continuing field work, and cooperative
agreements established with University of Alaska, Fairbanks and Alaska Pacific University to
create extent and volume change products over the next 3 years.

Fieldwork was conducted at DENA during two field campaigns in May and September, in
addition to a fixed wing over flight in March to search for surging glaciers. The May campaign
collected snow depth, snow density, glacier surface height, glacier stake height (in relation to the
glacier surface), and precise stake position data at each index station on Kahiltna and Traleika
Glaciers. The precise location of one survey monument on the lower Muldrow Glacier surface
was GPS surveyed to track changes in surface height and glacier velocity. The September
campaign collected glacier surface height, glacier stake height (in relation to the glacier surface),
and precise stake position data at each index station. In addition, a GPS survey on East Fork
Toklat Glacier collected glacier surface elevation data along a longitudinal profile, legacy mass
balance stake location and heights, and several points to map the terminus position. Panoramic
gigapixel photography was newly employed this year for several sites: 360 degree panoramas at
the index stations (spring and fall) and Muldrow Glacier monument (spring); panoramas were
taken from vantage points above the lower sections of East Fork Toklat, West Fork Cantwell
(spring and fall); and at one historic panorama point, at Oastler Pass, above the lower Muldrow
Glacier (spring).

A GPS survey conducted on East Fork Toklat Glacier shows dramatic thinning of over 120
meters (400 feet) since the 1950s (Figures F-1 and F-2).

Reduction of the mass balance data shows a negative net balance at both index stations on each
glacier (Figure F-3). The negative mass balance adds to the overall negative trend in the
cumulative balance since measurements started in 1991, although this year marks the reversal of
a shorter term positive trend since 2004 on Kahiltna Glacier with 2009 marking the same
reversal at Traleika. These long-term trends are represented by the altitude of the equilibrium
line altitude (ELA) which is calculated from the mass balance at an index stake and an estimated
balance gradient (Figure F-4). The ELA is chosen as the indicator for the overall balance/health
of the glacier for each year.

The surface speed of the Kahiltna Glacier at the index station was 195 m/year and 147 m/year at
Traleika. The surface speed at the index station appears to be decreasing through time since

1991 on Kahiltna and increasing at Traleika with an unprecedented acceleration between May and September 2010 (Figure F-5).

No glaciers were observed to surge this year.

Long-term monitoring of glaciers in CAKN will continue next year much the same as this past year following and refining the protocol and standard operating procedures that we developed this year (Adema and Burrows, in progress).

We will obtain gigapixel photography on a new suite of glaciers this year, including the Kahiltna Glacier terminus, Middle Fork Toklat Glacier, Polychrome Glacier. Along with the photography we plan to resurvey the termini of these glaciers and if possible completely re-map the Polychrome glacier.

Additional data at the index stations will aid in interpreting past years' data: 1) We will conduct more extensive GPS surveying of the glacier surface elevation in the vicinity of the index stations. This data will aid in interpreting past surveys, since these are spread out up to several hundred meters apart and from the index station coordinate. 2) If weather, time, and helicopter logistics allow we will conduct more extensive snow probing on the Traleika Glacier to explore patterns of snow accumulation and how representative the index stake is of the area of the glacier at which it resides.

Figure F-1. An oblique aerial view up the lower East Fork Toklat Glacier on September 14, 2010.
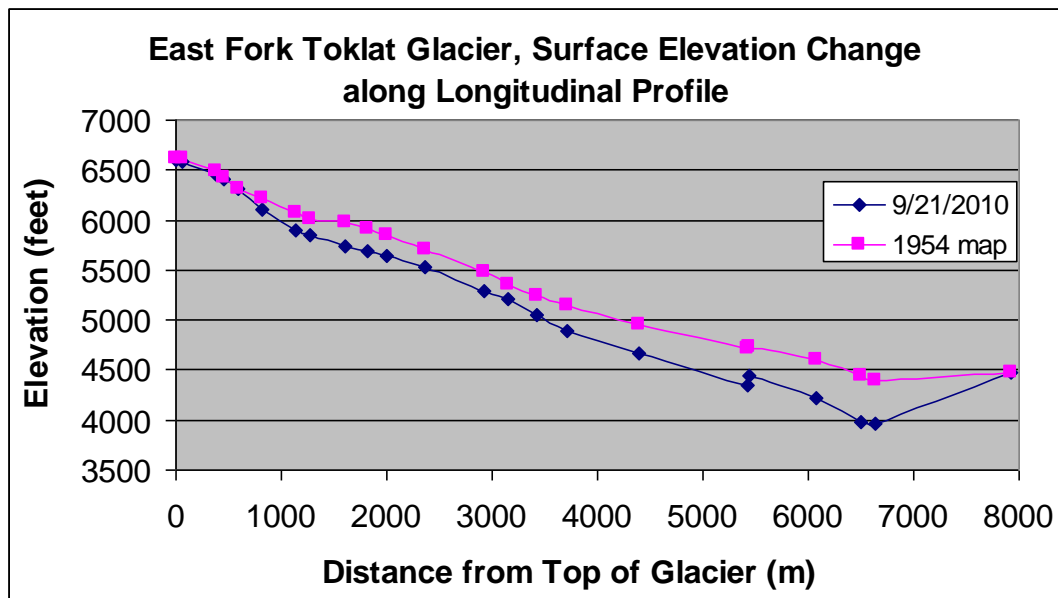
Figure F-2. Elevation of the longitudinal profile from the 1954 Healy B-6 USGS quadrangle and from the 9/21/10 GPS survey. Note the good agreement between control points on bedrock at the top and bottom of the profiles.
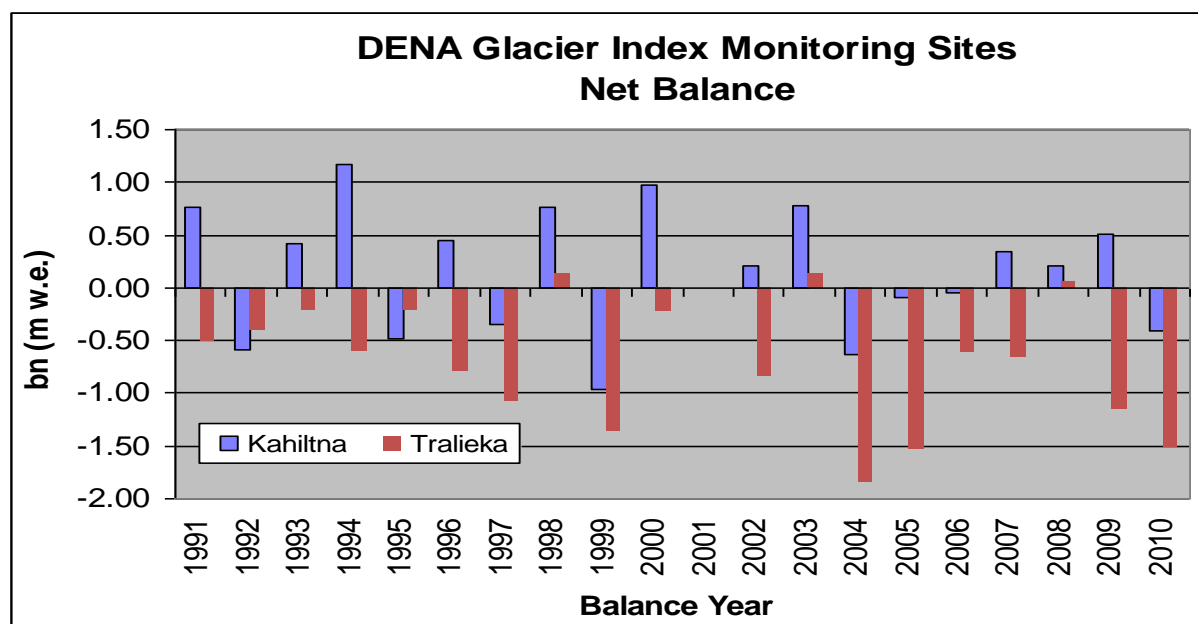
Figure F-3. Net balance at the index stakes on Kahiltna and Traleika Glaciers. Note that these values are NOT indicative of the balance of the entire glacier for the year, but they do give an indication of the relative magnitude of the balance of each glacier for the entire year.
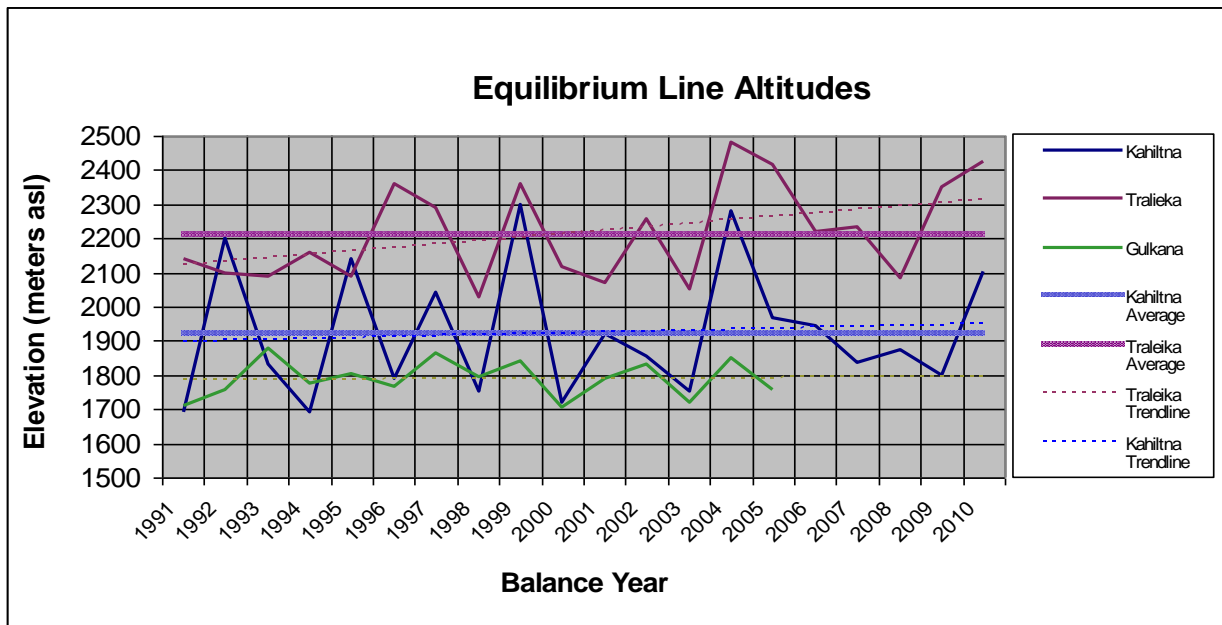
Figure F-4. The calculated ELAs at each glacier. These values serve as an index of the entire glacier net balance for each balance year, and are a good comparison with patterns and trends on Gulkana Glacier, which is monitored by the US Geological Survey.
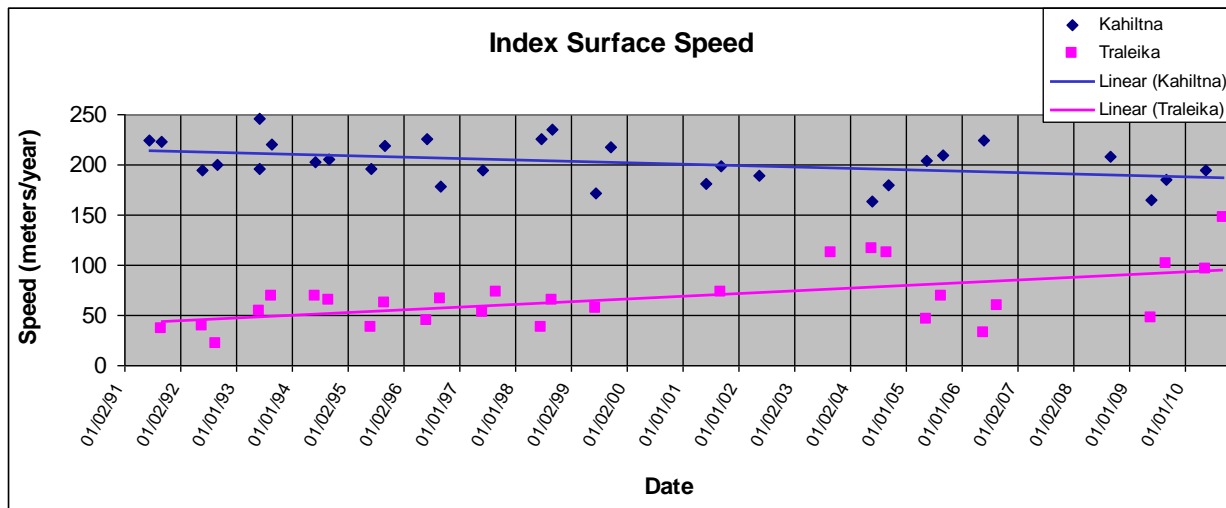
Figure F-5. Surface speed of the index stakes on Kahiltna and Traleika Glaciers since 1991. Note the anomalously high speed of Traleika in late 2010.

Appendix G – Report for Research Permit Reporting System

INVESTIGATOR'S ANNUAL REPORT
United States Department of the Interior

National Park Service

All or some of the information you provide may become available to the public.

OMB # (1024-0236)
Exp. Date (11/30/2010)
Form No. (10-226)

Reporting Year: 2010	Park: Denali NP & PRES	Select the type of permit this report addresses: Scientific Study

Name of principal investigator or responsible official: Guy Adema	Office Phone: 907-683-6356

Mailing address: Box 9 Denali, AK 99755 US	Office FAX Office Email guy_adema@nps.gov

Additional investigators or key field assistants (first name, last name, office phone, office email)
Robert Burrows, 907-683-6244, Rob_Burrows@nps.gov

Project Title (maximum 300 characters):
Glacier Monitoring in Denali National Park and Preserve

Park-assigned Study or Activity #: DENA-00730	Park-assigned Permit #: DENA-2006-SCI-0006	Permit Start Date: May 20, 2006	Permit Expiration Date: Dec 31, 2010

Scientific Study Starting Date: May 20, 2006	Estimated Scientific Study Ending Date: Dec 31, 2060

For either a Scientific Study or a Science Education Activity, the status is: Continuing	For a Scientific Study that is completed, please check each of the following that applies: ___ A final report has been provided to the park or will be provided to the park within the next two years ___ Copies of field notes, data files, photos, or other study records, as agreed, have been provided to the park ___ All collected and retained specimens have been cataloged into the NPS catalog system and NPS has processed loan agreements as needed

Activity Type:
Monitoring

Subject/Discipline:
Glaciers

Purpose of Scientific Study or Science Education Activity during the reporting year (maximum 4000 characters):

This study will document the conditions and trends of Denali's glaciers. A nested approach of landscape-scale observations and selected in situ measurements, the changing glacial system will be measured and documented. This effort is part of a larger natural resource monitoring program, first the Long-Term Ecological Monitoring Program, now the Central Alaska Network Monitoring Program. We hope to produce data and trends that will inform park management, glaciologists, and climate change researchers about the trends occuring at Denali.

Findings and status of Scientific Study or accomplishments of Science Education Activity during the reporting year (maximum 4000 characters):

See next page.

The National Park Service may not conduct or sponsor, and a person is not required to respond to, this collection of information unless it displays a currently valid OMB control number. (appformscif.doc; revised 04/13/2004) Page 1 of 2

Funding specifically used in this park this reporting year that was provided by NPS (enter dollar amount):	Funding specifically used in this park this reporting year that was provided by all other sources (enter dollar amount):
$10000	$0

List any other U.S. Government Agencies supporting this study or activity and the funding each provided this reporting year:

During 2010, three main program goals were accomplished: (1) a draft revised monitoring protocol with several additions and changes to the monitoring protocol was completed, (2) long-term monitoring continued for the 20th consecutive year, and (3) cooperative agreements established with University of Alaska, Fairbanks (UAF) and Alaska Pacific University (APU) to develop a glacier inventory for Alaska, focusing on a glacier extent and volume change products over the next 3 years (see separate RPRS report). Glacier related research included the second year of a three year study to assess the impacts of human waste on the Kahiltna Glacier with APU (see separate RPRS report), analysis of 2006 LiDAR data and a 1970s Washburn topographic map of Muldrow Glacier continued by UAF, and a UAF M.S. student conducted mass balance measurements and installed a weather station on the lower Kahiltna Glacier (see separate RPRS report).

Mass balance Fieldwork was conducted at Denali during two field campaigns in May and September in addition to a fixed wing overflight in March to search for surging glaciers. No surging glaciers were detected this year.

Field measurements indicate that the net balance (bn) at both index stations (Kahiltna and Traleika glaciers) and for the entirety of the glaciers was negative this year. The bn at the Kahiltna index stake was -0.41 meters water equivalent (m w.e.), which is 47% of the most negative bn measured to date. This is a 0.41 m w.e. decrease in the current positive cumulative balance of 3.00 m w.e., which is calculated since measurements started in 1991. The winter balance (bw) at the Kahiltna stake was 0.63 m w.e. (58% of average) and the summer balance (bs) was -1.03 m w.e. (108% of average). The equilibrium line altitude (ELA) is calculated to be 2104 meters this year with the bn calculated there as -0.41.

The bn at the Traleika Glacier index stake was -1.51 m w.e., which is 66% of the most negative bn measured to date. This is a further decrease in the negative cumulative balance of -13.26 m w.e., which is calculated since measurements started in 1991. The winter balance (bw) at the Traleika stake was 0.53 m w.e. (79% of average) and the summer balance (bs) was -2.04 m w.e. (155% of average). The equilibrium line altitude (ELA) is calculated to be 2425 meters this year with the bn calculated there as -0.96 m w.e.

The surface speed at the Kahiltna index station was 185 m/yr between 9/3/2009 and 5/19/10 and 195 m/yr between 5/19/10 and 9/14/10 (the average is 203 m/yr). The overall trend for Kahiltna appears to be decreasing through time since 1991. Traleika was 95.8 m/yr between 9/1/2009 and 5/18/10 and 147 m/yr between 5/18/10 and 9/12/10 (the average is 66.6 m/yr). The overall trend for Traleika appears to be increasing through time since 1991 and the summer speed is unprecedented in this period of measurement.

Panoramic gigapixel photography was newly employed this year for seven sites. In addition, a GPS survey on East Fork Toklat glacier collected glacier surface elevation data along a longitudinal profile, legacy

Appendix H – Report for Superintendent's Annual Report

Glacier Waste Monitoring
An agreement was developed with Alaska Pacific University research Dr. Michael Loso to assess effects of human waste on Mt McKinley. The three-year project will assess the biological risk to backcountry visitors and related glacier dynamics in order to inform mountain waste management practices. In 2010, a graduate student collected snow and water from various areas on and around the West Buttress climbing route for analysis of bacterial effects on the environment. The student also conducted extensive searches for historic human waste, but wasn't able to find any after significant effort. The work built on prior work by an APU student established the surface movement field in the area of the Kahiltna base camp. At the end of 2011, we hope to add a glacier flow model. These data taken together will inform future management of waste on Mt McKinley.

Glacier Monitoring
Cooperative agreements were established with University of Alaska, Fairbanks and Alaska Pacific University to create glacier extent, inventory, and volume change products for Alaska national parks (including DENA and WRST) over the next 3 years. We continued development of a modern protocol document and standard operating procedures. Fieldwork was conducted at Denali during two field campaigns in May and September in addition to a fixed wing over flight in March to search for surging glaciers. No surging glaciers were detected this year. Field measurements indicate that the net balance at both index stations and for the entirety of the glaciers was negative this year. The negative mass balance adds to the overall negative trend in the cumulative balance since measurements started in 1991, although this year marks the reversal of a shorter term positive trend since 2004 on both glaciers. The surface speed at the index station appears to be decreasing through time since 1991 on Kahiltna and increasing at Traleika with an unprecedented acceleration between May and September 2010. Panoramic gigapixel photography was newly employed this year for several sites. In addition, a GPS survey on East Fork Toklat Glacier collected glacier surface elevation data along a longitudinal profile, legacy mass balance stake location and heights, and several points to map the terminus position. The survey on East Fork Toklat shows continued thinning of 30 to 140 meters. Glacier monitoring program highlights and results were presented at the Northwest Glaciologists meeting in Fairbanks, AK on October 8, 2010.

Appendix I – Logistics Notes

Helicopter logistics in the fall were complicated somewhat by the requirement in the IHOG to have a Helicopter Manager on board the aircraft for landing at unimproved landing zones when the highest level of certified training of the other passengers is a only a B3. The helicopter available for the fall flights had limited allowable payload, so sometimes this meant extra flights. When the certified level of training for those others (the glacier monitoring personnel) is Helicopter Crewmember then the requirement for the on board Helicopter Manager is not needed. Therefore, in future years, staff should have at the least the Helicopter Crewmember or Helicopter Manager certifications current.

The new index stakes placed in 2010 were constructed of shorter 2-meter sections (3-meter sections have been used in the past). The stake sections were shortened to fit in the belly pod of the Hughes 500 helicopter, as strapping the longer stakes to the skids as has been done in the past was decided to be too unsafe.

The individual photo files and stitched gigapixel panoramas are kept and backed up in digital form on the computer with service tag number: 4SY8CG1 (currently in the Resources Annex at DENA headquarters).

The most marked change to the protocol for index station measurements is to abandon recording GPS position on the top of the stake. We decided the extra effort and time to take this measurement did not justify the added precision.

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